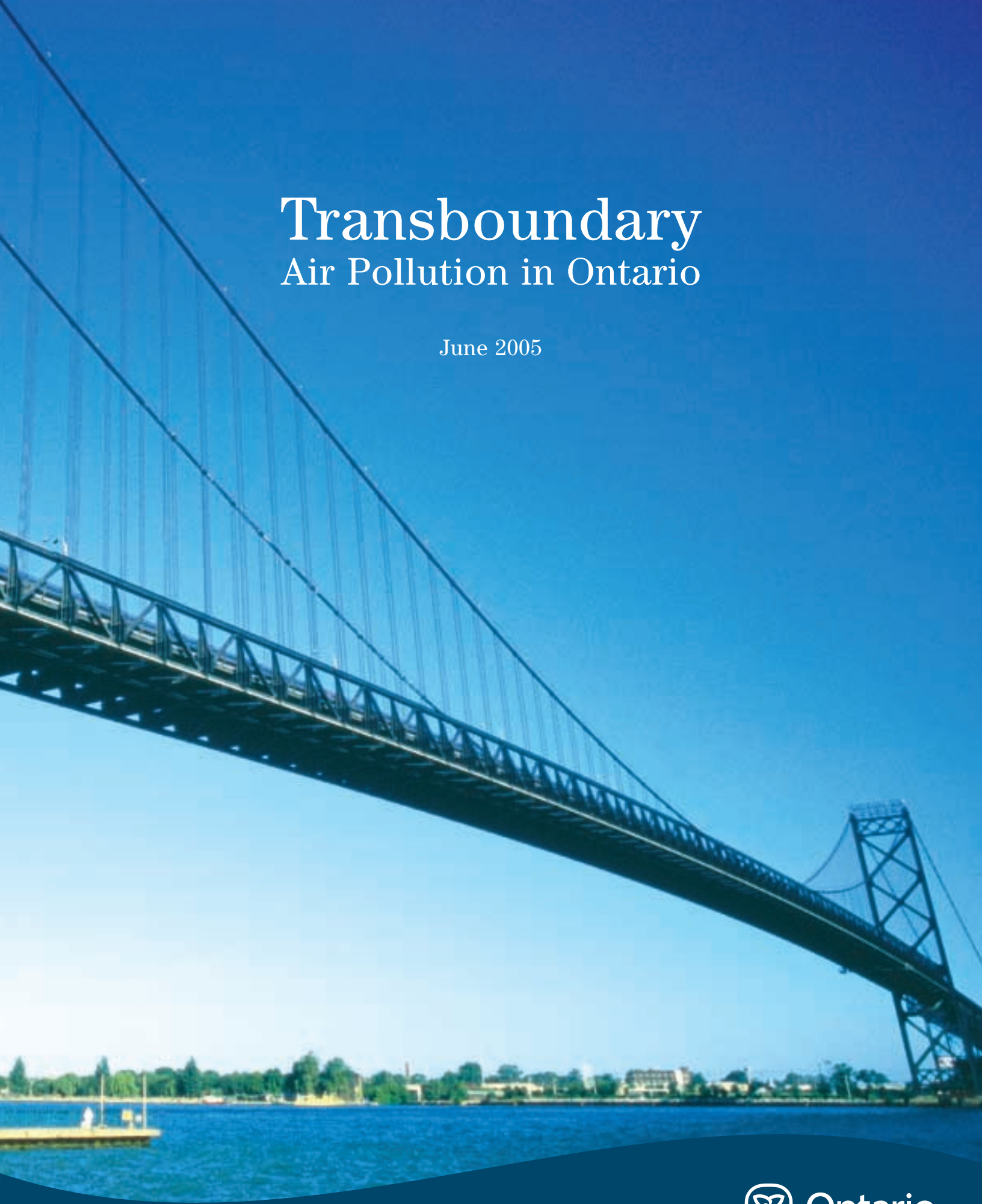
Transboundary
Air Pollution in Ontario

June 2005



Protecting our environment.

Ontario

Ontario Ministry of the Environment
June 2005

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EXECUTIVE SUMMARY

A significant amount of Ontario's smog originates from emission sources in the United States (U.S.). Although data analysis strongly indicates that neighbouring U.S. states continue to be major contributors to elevated levels of ground-level ozone and fine particulate matter ($PM_{2.5}$), Ontario acknowledges and takes responsibility for its local emissions and its role as a contributor to the regional transport of air pollution.

This report provides a current review of transboundary air pollution impacts from an Ontario perspective. Drawing on Ontario's extensive air quality data, and recent air quality modelling work, the document examines the role of transboundary air pollution in Ontario, specifically the impacts of smog (both ground-level ozone and fine particulate matter) and an assessment of the human health and economic costs. The report also examines the impact of Ontario's emissions on other jurisdictions. Acid deposition and mercury impacts are reviewed as these are current and emerging regional air issues of concern to Ontarians and adjacent jurisdictions. Emission control programs, initiatives and agreements that are being undertaken or considered to address these transboundary problems are also highlighted.

Impact of U.S. Transboundary Air Pollution on Human Health in Ontario

Based on 2003 demographics, Ontario is burdened with almost $9.6 billion in health and environmental damages each year due to the impact of ground-level ozone and fine particulate matter. Of this total, approximately 55 per cent is attributable to U.S. emissions. The remainder is attributable to Ontario emissions related to human activity. These results are largely based on recent health studies that suggest smog pollutants have very low or no health thresholds.

Health damages comprise approximately 70 per cent of the total economic damages or about $6.6 billion per year, of which $3.7 billion is attributed to U.S. emissions and $2.9 billion to provincial air pollution. The great majority of the economic losses associated with health damages are attributable to premature mortality. Of a predicted 4,881 premature deaths, 56 per cent or 2,751 are associated with U.S. emissions, and more specifically with $PM_{2.5}$. Health care costs comprise the next greatest proportion of the economic damages associated with health impacts. All Ontario citizens, as a result of increased demand on health care resources, incur these costs.

The distribution of these damages and the proportions attributable to the two sources vary considerably among the various regions of the province. As expected, southwestern Ontario experiences a large proportion of damages attributable to U.S. emissions, whereas the greatest impacts of air pollution originating in Ontario are felt in South Central Ontario. The economic damages incurred in the South Central Ontario area, which includes the Greater Toronto Area (GTA) and other major population centres in the Golden Horseshoe, represent 61 per cent of the total damages.

Observational Evidence of Transboundary Impacts

Detailed analysis of smog levels over the past three decades, incorporating meteorological information, indicates that elevated levels of ground-level ozone and fine particulate matter are often associated with distinct weather patterns that affect the air quality in the lower Great Lakes region. Such weather conditions are generally associated with slow-moving high pressure systems south of the lower Great Lakes. This results in long-range transport of smog pollutants from neighbouring U.S. industrial and urbanized states during warm south to south-westerly flow conditions. For Ontario, elevated smog levels have been strongly linked to long-range transport and transboundary flow from the highly industrialized and urbanized areas of the American Mid-West and Ohio Valley Regions.

The precursor emissions to ground-level ozone are nitrogen oxides (NO_x) and volatile organic compounds (VOC). Ontario's NO_x emissions in the regional air shed (comprised of Ontario and 22 neighbouring mid-western and eastern U.S. states) are about 6 per cent of the total NO_x emitted and about 7 per cent of the total anthropogenic VOC emitted. During widespread smog episodes, the U.S. contribution to ozone excluding background levels is expected to be as much as 90 per cent in Ontario cities and towns on the northern shore of Lake Erie, the eastern shore of Lake Huron and in the extreme southwest near the U.S. border.

Like ozone, $PM_{2.5}$ can be transported many hundreds of kilometres from its point of origin. Neighbouring U.S. states release approximately 28 times as much primary fine particulate matter as does Ontario, mainly from on-road transportation and point sources such as industry.

Acid rain continues to be a significant environmental problem that affects large areas of the U.S. and Canada. Airborne acidic pollutants are also transported by large-scale weather systems thousands of kilometres from their point of origin before being deposited. The 2004 Canadian Acid Deposition Science Assessment report reaffirmed the significant contribution to acid deposition in eastern Canada (which includes the province of Ontario) from U.S. sources. Canadian sources in the region emit less than 10 per cent of total sulphur dioxide (SO_2) and NO_x emissions. However, the same area of eastern Canada receives roughly 30 per cent of the total sulphate and nitrate wet deposition in eastern North America.

Toxic or hazardous pollutants are another critical air issue for Ontarians having a detrimental effect on the environment and human health. These pollutants may be transported short distances, while others are carried regionally, continent-wide or globally. It is also complicated by the "grasshopper effect" (after deposition in one location, contaminants become airborne again, and are transported and deposited in another location). Mercury is an example of such a pollutant of growing concern in Ontario.

Although mercury is a global problem, the precipitation concentrations in Ontario and at most sites in the U.S. and Canada are higher than global background values. Regional and local mercury emissions from the U.S. and Canada are contributing to mercury deposition in Ontario. However, mercury emissions in the U.S. have decreased by about 50 per cent from 1990 levels to 104 tonnes in 1999. As of 2000, Ontario has reduced its atmospheric mercury emissions by 78 per cent of 1988 levels. In 2001, atmospheric releases from human activity in Ontario were estimated to be 1.9 tonnes.

Modelling Air Pollution in Ontario and Assessing the Transboundary Contribution

Atmospheric models have been developed to predict pollutant behaviour in the atmosphere. They ideally include all relevant atmospheric processes and are the only tools available which allow quantitative assessment of the impact of pollutants from individual sources or groups of sources. Such models can be used to quantify the impact of transboundary air flows on Ontario and to examine the flow of air pollution into and across Ontario. Emissions of smog precursors from a region that included Ontario, Quebec and that part of the United States east of the Mississippi, and south to include Tennessee and North Carolina, were used with meteorological data sets for specific time periods to assess source contributions to ambient pollutant levels.

Based on a recent assessment using the Eulerian modelling system CMAQ for the period May to September 1998, the study concluded the setting of Ontario emissions to zero on high ozone concentration days (days when 8-hour running average ozone concentrations were above the Canada-wide Standard (CWS) reference level of 65 ppb) would have reduced ambient ozone concentrations by 1 per cent in Windsor, 9 per cent in the Greater Toronto Area (GTA), 16 per cent in Oshawa and 7 per cent in Kingston. That is, on those days during the summer of 1998, when modelled ozone levels in the province were above the CWS, Ontario emissions contributed to at most 16 per cent of the problem. The largest contribution due to Ontario's emissions was downwind of the Greater Toronto/Hamilton areas. Ontario's contribution to upper New York state and Vermont/New Hampshire was approximately 3 per cent.

For particulate matter (PM), the Ontario contribution is highest in the GTA at approximately 50 per cent during a smog episode where the daily average $PM_{2.5}$ levels exceed the CWS reference level of 30 $\mu g/m^3$. When the results of the air quality modelling of $PM_{2.5}$ are averaged over all days throughout the five-month period and Ontario emissions due to human activity are set to zero, the Ontario contribution to the GTA exceeds 50 per cent. Other communities from Windsor to Ottawa had reductions in $PM_{2.5}$ concentrations by 20 to 40 per cent when Ontario emissions were set to zero. The remainder of the $PM_{2.5}$ concentrations is contributed by both U.S. emissions and background levels, with the majority attributed to U.S. emissions. This study indicates that significant reductions in PM concentration(s) can only be achieved by reducing primary and precursor emissions across the entire domain.

Reductions in Canadian emissions alone are less effective in reducing ozone and particulate matter concentrations in the province, especially during the summer months

when compared to the winter months. In winter months, a reduction in Canadian emissions is much more effective since the atmosphere would be more stagnant, preventing the transport of emissions, and consequently having a greater impact in their local area.

Ontario understands that it is not only the recipient of transboundary air pollution, but the province contributes to the problem in downwind jurisdictions such as Quebec, the U.S. New England states and the Canadian maritime provinces. Modelling results show that Ontario's emissions contribute to approximately 16 per cent of $PM_{2.5}$ loadings on average days in Quebec and at most, 12 per cent on days when ozone and $PM_{2.5}$ concentrations were high. Ontario emissions contribute up to approximately 20 per cent of the $PM_{2.5}$ loadings on average days in the upper state New York area and about 7 per cent in Vermont and New Hampshire.

Programs, Initiatives and Agreements to Address Transboundary Air Pollution

Ontario's approach to reducing smog addresses the diversity of emission sources that contribute to the formation of smog in Ontario from both local and transboundary pollution. The government is following a multi-faceted, comprehensive smog reduction approach that addresses multiple pollutants which provides encouragement to all sectors of the economy, and targets key emission sectors such as electricity generation, transportation, industry and residential.

The government's key smog-causing emission reduction activities can be grouped into the following eight categories: (1) Regulatory initiatives; (2) Government leadership; (3) Conservation; (4) Clean energy incentives; (5) Public education and outreach; (6) Encouraging non-regulatory commitments; (7) Building capacity; and (8) Agreements between Ontario and other provincial/state jurisdictions. Ontario has a long history of encouraging the federal government to take action where federal emission reduction tools would be most efficient, and to initiate discussions with the U.S. on transboundary anti-smog actions when necessary and appropriate.

Action in the U.S. that relates to potential air quality improvements in Ontario fall under activities of the U.S. Clean Air Act and recent initiatives of the EPA such as the U.S. New Source Review Program, and the new U.S. Clean Air Rules.

There are also joint Canada-U.S. actions such as the Canada-U.S. Air Quality Agreement that has been established to address transboundary pollution vis-a-vis the Acid Rain Annex and the Ozone Annex.

In June 2004, the government released *Ontario's Clean Air Action Plan* (CAAP). The CAAP provides background information on smog, and describes Ontario's smog reduction approach. It also includes current and proposed initiatives such as the commitment to close coal-fired generation in Ontario by replacing them with cleaner sources of power.

Concluding Remarks

Long-range transport and transboundary flow of air pollutants play a significant role in air quality considerations on a regional scale. This has the potential to do extensive damage to natural ecosystems and the physical environment in addition to the significant impact from health and socio-economic perspectives.

In response to these threats posed by the regional and transboundary air issues, Ontario, Canada and the U.S. have acted to address air pollution through the implementation of emission control programs, cooperative efforts, bi-national agreements and other air initiatives. These collaborations have made several gains however, air pollution and its transport remains a complex issue which requires further study and assessment to understand how we can effectively manage it presently and in the future.

The large contribution from U.S. emissions and background ozone presents a significant challenge. This challenge has a bearing on all of us as air pollution clearly has no borders. Responsibility, leadership, cooperation and accountability must be shared and recognized by all jurisdictions and acknowledged if we are to make progress in improving the quality of the air we breathe and our health.

Regional air issues and the transboundary nature of the problem are significant, and with persistent, collaborative and harmonious efforts we can all benefit from cleaner air.

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1.0 Introduction

This report provides a current review of transboundary air pollution impacts from an Ontario perspective. Drawing on Ontario's extensive air quality data, and recent air quality modelling work, the document examines the role of transboundary air pollution in Ontario, specifically the impacts of smog (both ground-level ozone and fine particulate matter) and an assessment of the human and economic costs of such impacts. The report also examines the impact of Ontario's emissions on downwind jurisdictions. Acid deposition and mercury impacts are reviewed as these are current and emerging regional air issues of concern to Ontarians. Emission control programs, initiatives and agreements are being undertaken or considered to address these transboundary problems are also highlighted.

The impact of air pollution on humans and the natural environment in Ontario has been continuously documented over the past three decades. Since the early 1970s Ontario has been monitoring air quality across the province to assess the state of Ontario's air and to implement appropriate abatement programs to reduce the burden of air pollutants and to address key air issues as required. The outcome of these activities shows that levels of common air pollutants such as sulphur dioxide, carbon monoxide and nitrogen dioxide have significantly decreased across Ontario over the years despite increases in population, economic activity and vehicle-kilometres travelled. Such improvements can be related to, for example, significant reductions in emissions from automobiles using on-board controls and the clean up of a broad range of industrial and commercial sources.

Despite such good news, air pollution remains a concern for many people who live in Ontario and who are exposed to undesirable levels of pollutants such as ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$), the key components of smog. This is especially evident in southern Ontario where significant amounts of Ontario's smog originate from sources in the United States. Moreover, with increasing advances in health sciences, various researchers and organizations [1] regularly update the toll on human health and well being in Ontario caused by the exposure to smog.

Air pollution in Ontario comes from various sources including stationary sources such as factories, power plants, and smelters; mobile sources such as cars, buses, trucks, planes, marine vessels and trains; and finally, natural sources such as forest fires, windblown dust and biogenic emissions from vegetation. Many pollutants, including those associated with smog, remain in the atmosphere for long periods of time. These air pollutants are generated both locally and regionally, and, with winds, can travel hundreds of kilometres from province to province and country to country, affecting areas far removed from the source of the pollution. Long-range transport and transboundary flow of air pollutants thus have a significant role in air quality considerations on a regional

[1] Ontario Medical Association. *The illness costs of air pollution in Ontario: a summary of findings*. July 2000.
City of Toronto. *Toronto Public Health: Air pollution burden of illness in Toronto: 2004 Summary*. July 2004.

scale. Furthermore, this has the potential to harm millions of people and do extensive damage to natural ecosystems and the physical environment.

Based on air quality measurements over the past three decades, it has been readily apparent that transboundary air pollution is a significant problem in Ontario. This was demonstrated in the science during the lead-up to the development of acid gas reduction strategies such as Ontario's *Countdown Acid Rain Program* which was initiated in 1986. Airborne acidic pollutants were often transported by large-scale weather systems thousands of kilometres from their point of origin before being deposited. For example, sulphur dioxide and nitrogen dioxide emissions from the American mid-west and the Ohio Valley region were shown to impact on the pristine areas of northeastern U.S. and southeastern Canada, including Ontario.

Indeed, studies over the years indicate that areas of southern Ontario often experience the highest levels of acidic deposition, ground-level ozone, fine particulate matter and hazardous air pollutants in eastern Canada. Elevated levels of these pollutants in southern Ontario have been strongly linked to long-range transport and transboundary flow from heavily industrialized and urbanized areas upwind. These air issues are also often inextricably influenced by one another and thus need to be addressed in an integrated manner through inter-agency approaches and multi-disciplinary teams within agencies. Reductions in emissions of combustion related sources have co-benefits for air issues such as acid rain, smog, heavy metals and global warming. An example of an integrated approach to address these air issues and the transboundary nature of the problem is the use of a unified regional air quality modelling system to address multi-pollutant and multi-use applications.

The importance of transboundary air pollution in Ontario was also recognized by the Canadian Council of the Ministers of the Environment (CCME) in 2000 when they approved the Canada-wide Standards (CWS) for ground-level ozone and particulate matter. For ozone, Annex B of the standard states that *"For the province of Ontario, a 45 per cent reduction in NO_x[2] and VOC[3] emissions from 1990 levels by 2010 or earlier, subject to successful negotiations this fall with the U.S. for equivalent reductions, will be considered the province's appropriate level of effort towards achieving the ozone CWS. Any remaining ambient ozone levels above the CWS in Ontario will be considered attributable to the transboundary flow from the U.S. of ozone and its precursor pollutants."*[4] No similar statement was made for particulate matter but the need to differentiate the transboundary contribution of particulate matter to the Ontario airshed (and others across the country) was noted.

Ongoing efforts to quantify the impact of transboundary air pollution flows on Ontario are being conducted to clarify Ontario's commitments under the two Canada-wide Standards and the Canada-U.S. Air Quality Agreement of 1991 (including its Ozone

[2] NO_x – oxides of nitrogen; the sum of nitric oxide and nitrogen dioxide
[3] VOC – volatile organic compounds
[4] Guidance Document on Achievement Determination, Canada-wide Standards for Particulate Matter and Ozone, Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. 2002 www.ccme.ca

Annex signed in 2000). In this regard, the Ontario Ministry of the Environment (MOE) has conducted with other agencies and on its own, numerous mathematical modelling studies to examine the flow of air pollution into and across Ontario.

2.0 Ontario's Air Quality

Over the past three decades, air quality measurements across Canada, including Ontario, indicate significant reductions in levels for most of the common air contaminants. For example, average sulphur dioxide and carbon monoxide concentrations in 2003 were approximately 86 per cent (Figure 2.1) and 88 per cent lower than levels reported in 1971, respectively. Average nitrogen dioxide concentrations decreased by 26 per cent from 1975 to 2003.

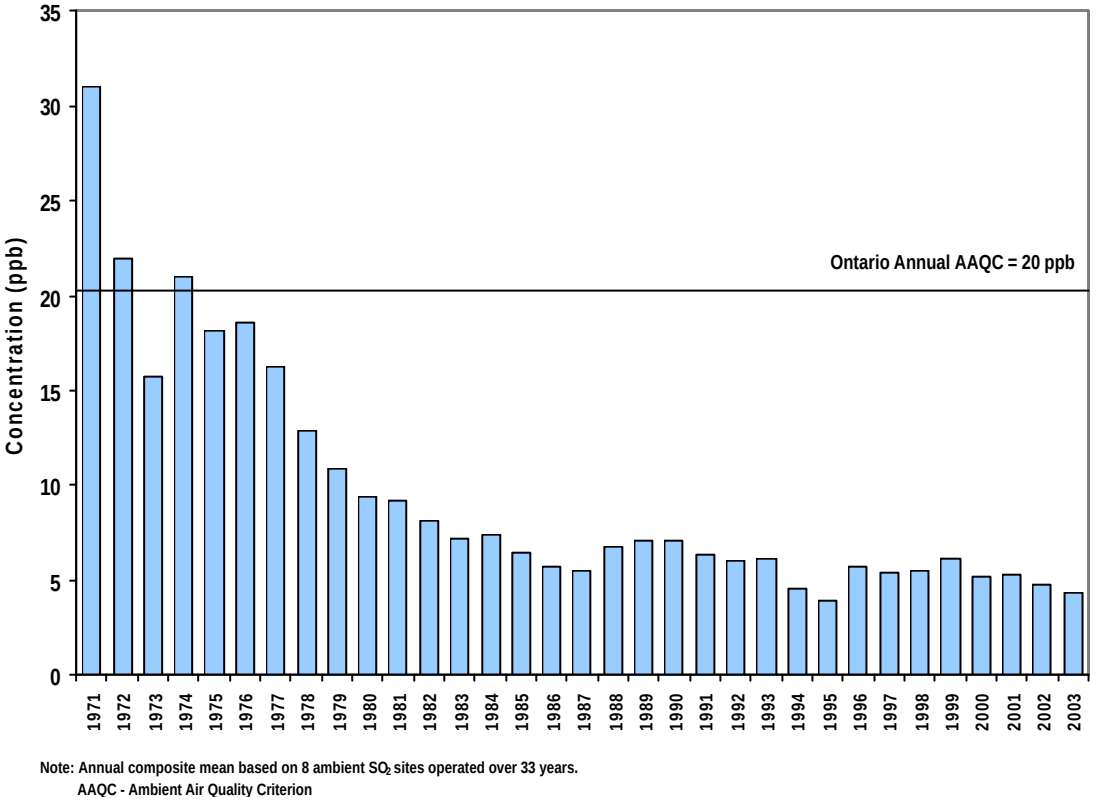


Figure 2.1: 33-Year Trend of Sulphur Dioxide Concentrations in Ontario (1971 – 2003) (source: Ontario Ministry of the Environment)

Despite such improvements, air pollution continues to be a serious concern to Ontarians, especially for contaminants such as ground-level ozone and fine particulate matter which continue to exceed standards/criteria and impact significant portions of the general population. In addition, there are concerns raised in light of recent advances in health and environmental sciences. The latest studies indicate areas of southern Ontario experience the highest levels of acidic deposition, ground-level ozone, fine particulate matter and hazardous air pollutants in eastern Canada. These air issues are of a regional nature that impact areas typically up to thousands of kilometres distant from sources and hence all have significant transboundary impacts on Ontario.

From a Canadian perspective, identification and assessment of ozone and fine particulate matter impacts, both individually and in the context of smog, in Ontario can be seen from recent summary analysis of monitored data. For example, monitored levels of ozone and fine particulate matter in 2002 for Canada (Figures 2.2 and 2.3) indicate that the smog problem is most severe in Ontario. Data analyses for the nation as a whole indicate that the daily 8-hour ozone maxima exceed 65 parts per billion and the 24-hour average $PM_{2.5}$ concentrations exceed 30 micrograms per cubic metre ($\mu g/m^3$) most often in Ontario, followed by Quebec in eastern Canada. These target levels form the basis for the Canada-wide Standards (CWS) for $PM_{2.5}$ and ozone that are to be met by 2010. The metric for meeting the CWS for ozone is the 3-year average of the annual 4th highest of the daily maximum 8-hour average ozone concentrations and for $PM_{2.5}$, the 3-year average of the annual 98th percentile of the 24-hour average $PM_{2.5}$ concentrations.

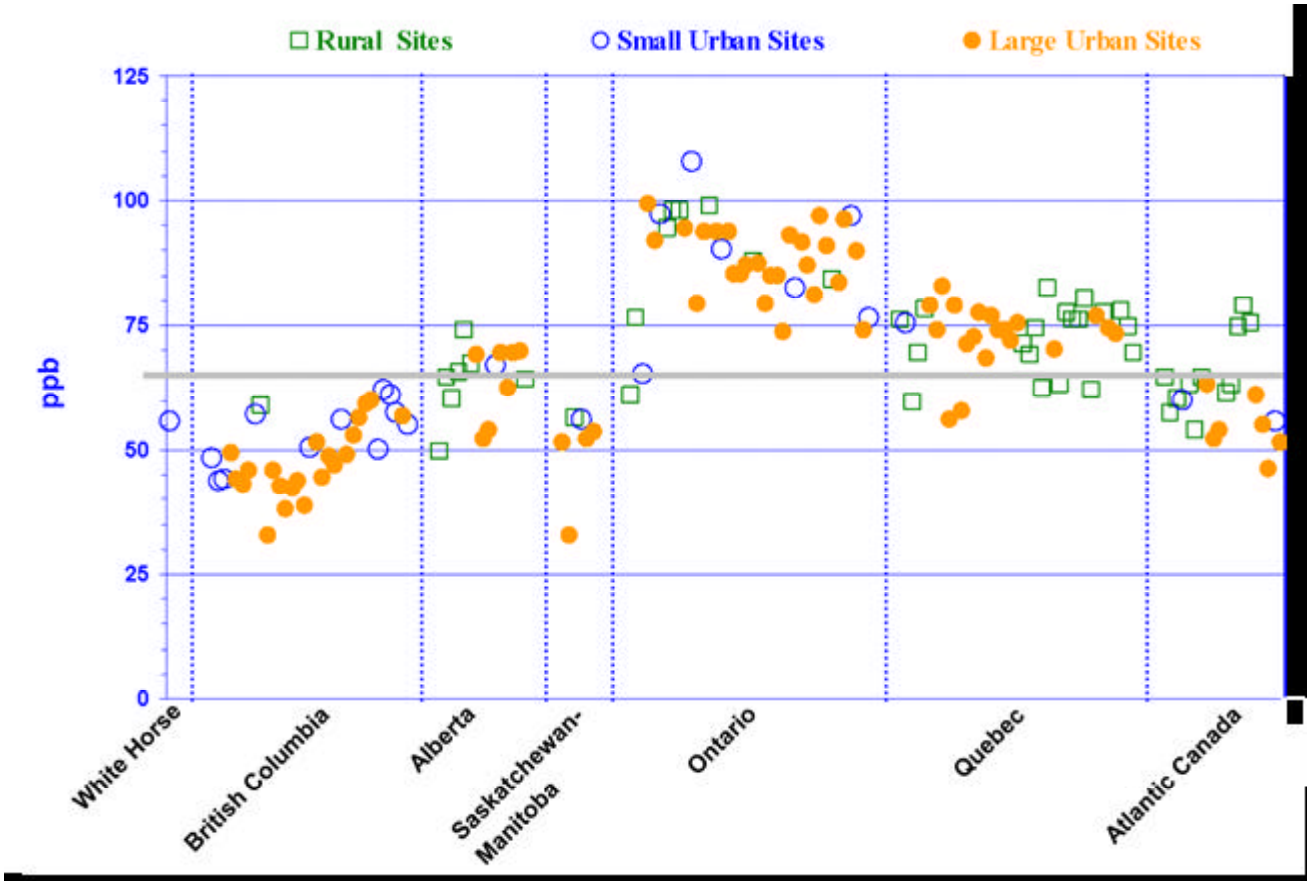


Figure 2.2: 2002 4th Highest Daily Maximum 8-hour Ozone
(source: Environment Canada)

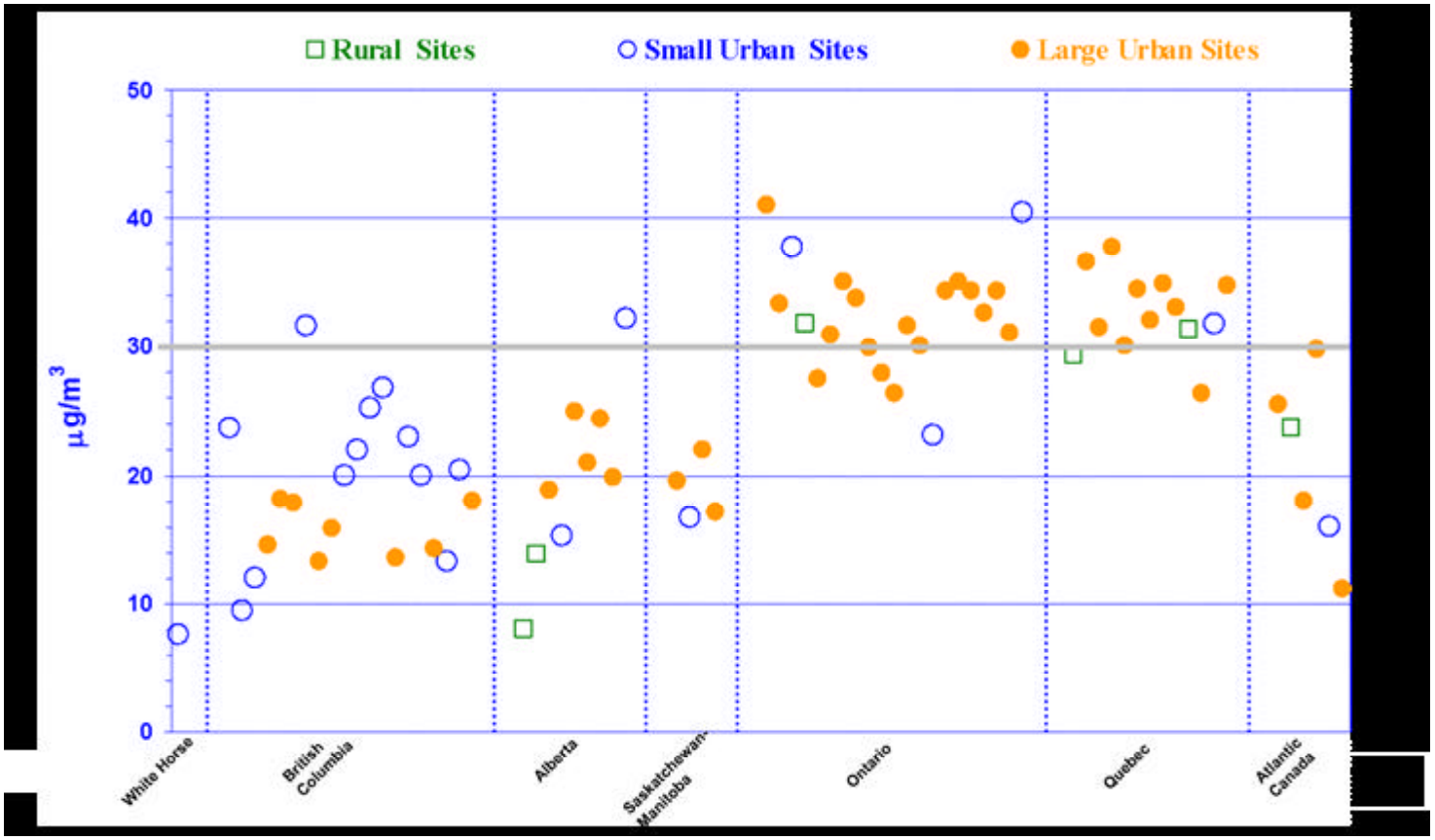


Figure 2.3: 2002 98^{tn} Percentiles of the Daily 24-hour $PM_{2.5}$
(source: Environment Canada)

The fact that elevated levels of ozone and fine particulate matter occur most often over southern Ontario is also well documented. For example, in December 2004, the Ontario Ministry of the Environment released its 33rd Annual Air Quality in Ontario report. The report summarizes province-wide monitoring of ambient air quality in 2003. Once again results indicate that the provincial ambient air quality criteria (AAQC) for nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2) were not exceeded at any of the ambient sites in 2003. Further, as in previous years, ozone (O_3) and fine particulate matter ($PM_{2.5}$), the main components of smog, continued to exceed ambient criteria levels and reference levels. In 2003, the one-hour AAQC for ozone (80 parts per billion over 1-hour) was exceeded at 38 of 39 ambient air monitoring stations on at least one occasion. The annual one-hour maximum concentrations of ozone continue to show a decrease over the past 24 years whereas an increasing trend in ozone means was observed during the same period. For fine particulate matter, the reference level[5] of 30 µg/m^3 for a 24-hour period (based on Canada-wide Standards) was exceeded at least once at all 27 sites across Ontario. Moreover, data analysis strongly indicates that neighbouring U.S. states continue to be significant contributors to elevated levels of ozone and $PM_{2.5}$ in

[5] Ontario has no AAQC for fine particulate matter ($PM_{2.5}$). The $PM_{2.5}$ reference level is based on the Canada-wide Standard (CWS) of 30 µg/m^3 over 24 hours. The official CWS for $PM_{2.5}$ is 30 µg/m^3, 24-hour averaging time, based on the 98th percentile annual ambient measurement averaged over three consecutive years.

southern and central Ontario during the traditional smog season, May to September. The report also recognized that the contributions from long-range transport and transboundary movement need further assessment, and that continued monitoring is required to evaluate air quality trends to determine the effectiveness of emissions reduction and abatement strategies.

Numerous researchers have studied the impact of airborne acidic pollutants on Ontario over the past two decades. Sulphur dioxide and nitrogen oxide emissions from the American mid-west and the Ohio Valley region have been shown to impact the areas of southern and eastern Ontario. In 1985, significant efforts were initiated to reduce the amount of sulphate in precipitation to a target level of 20 kilograms per hectare per year (kg/ha/yr) in order to protect all but the most sensitive aquatic ecosystems from acidification. This target was used to develop federal-provincial and international sulphur dioxide agreements. Current trends from the acid deposition network in Ontario indicate that the highest wet deposition (greater than 40 kg/ha/yr) is no longer evident over Ontario. The area previously identified as moderately high deposition (30 to 40 kg/ha/yr) has been reduced significantly and the area bounded by 20 kg/ha/yr has decreased significantly over the past twenty years. These reductions in wet sulphate deposition, and subsequent lowering of acidity in rain, are largely attributed to the significant reductions in sulphur dioxide emissions that have occurred in eastern Canada and the United States. The nitrate component of acid rain, largely influenced by nitrogen dioxide, is an area of growing importance and of emerging concern. In addition, a related concern over southern Ontario is that of acid aerosols, as sulphate and nitrate particles add to the burden of health-damaging respirable particles.

Toxic or hazardous air pollutants are another critical air issue for Ontarians, having an effect on human and environmental health. It includes a range of chemicals such as heavy metals, polychlorides, agricultural pesticides and persistent organic pollutants (POPs). The atmosphere has long been recognized to be a significant pathway for toxic contaminant deposition. Some of these are transported short distances, while others are carried regionally, continent wide or globally. It is also complicated by the "grasshopper effect[6]" (after deposition in one location, contaminants become airborne again, and are transported and deposited in another location). An example of one such pollutant of growing concern in Ontario is that of mercury. This pollutant occurs naturally as elemental mercury and in organic and inorganic compounds. The fact that it can persist long enough in the atmosphere suggests that it can be transported over large regions, if not globally. Thus, there is a need to understand the linkages between significant source regions and transboundary receptor areas of mercury especially in the Ontario context.

[6] Grasshopper Effect: Persistent and volatile pollutants – including certain pesticides, industrial chemicals and heavy metals – evaporate out of the soil in warmer countries where they are still used, and travel in the atmosphere toward cooler areas, condensing out again when the temperature drops. The process, repeated in "hops", can carry them thousands of kilometres in a matter of days. Canada's cold climate puts it at the receiving end of this process, with measurable concentrations of DDT, toxaphene, chlordane, PCBs and mercury found in both the Great Lakes and the Arctic (source: Environment Canada).

A more detailed overview of these pollutants (including particle composition) that is associated with regional air issues, and that can be linked to transboundary impacts on Ontario, is presented in the following sub-sections.

2.1 Ground-Level Ozone (O_3)

Ground-level ozone, one of the key components of smog, is a gas formed when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react in the presence of sunlight. While ozone at ground level is a major environmental and health concern, the naturally occurring ozone in the stratosphere shields the earth from harmful ultraviolet radiation.

The formation and transport of ground-level ozone are strongly dependent on meteorological conditions. Changing weather patterns contribute to short term and year-to-year differences in ozone concentrations. In Ontario, elevated concentrations of ground-level ozone are generally recorded on hot, sunny days from May to September, between noon and early evening, and are most commonly associated with southerly winds.

2.1.1 Precursors of Ozone

Ground-level ozone is not emitted directly into the atmosphere but rather formed from chemical reactions between VOCs and NO_x in the presence of sunlight. Sources of Ontario's VOC emissions from human activity mainly include transportation, such as road vehicles, and the use of general solvents. Sources of anthropogenic NO_x mainly include transportation, power plants, primary metal production and incineration.

Nitrogen Oxides (NO_x)

Nitrogen oxides (NO_x) consist of nitric oxide (NO) and nitrogen dioxide (NO_2). NO is a colourless, odourless gas, while NO_2 is a reddish-brown gas with a pungent and irritating odour. Nitric oxide is highly reactive, oxidizing rapidly in the atmosphere to form NO_2. Nitrogen dioxide is a lung irritant and can increase the chance of respiratory illness by lowering resistance to infection. People afflicted with asthma and bronchitis are generally more sensitive. In addition to reactions with VOCs that form ozone, nitrogen dioxide reacts in the air to form organic nitrates, and gaseous nitric acid (HNO_3) which, when deposited, contributes to lake acidification. Nitric acid can corrode metals, fade fabrics, degrade rubber, and damage trees and crops. Nitrates are also a major contributor to the formation of fine particulate matter.

Almost all NO_x emissions originate from human activities related to fossil fuel combustion of some type. In Ontario, as in many jurisdictions of eastern North America, the transportation sector accounts for a significant fraction of these emissions. In 2000, approximately 37 per cent of NO_x emissions in Ontario were attributed to the on-road transportation sector. For neighbouring U.S. states as a whole, on-road transportation also accounted for a significant portion of the NO_x emissions, approximately 37 per cent

in 1999. Of the remaining 63 per cent in Ontario, 37 per cent came from area sources and 26 per cent from point sources. Point sources made up 40 per cent, and area sources accounted for 23 per cent of NO_x emissions in the case of neighbouring upwind U.S. states. A detailed breakdown by source type and emission rates is illustrated in Figure 2.4. In the Ontario and neighbouring U.S. airshed, Ontario's NO_x emissions account for approximately 6 per cent of the combined total emitted. Detailed contribution by sector for Ontario and neighbouring U.S. states is shown in Figure 2.5.

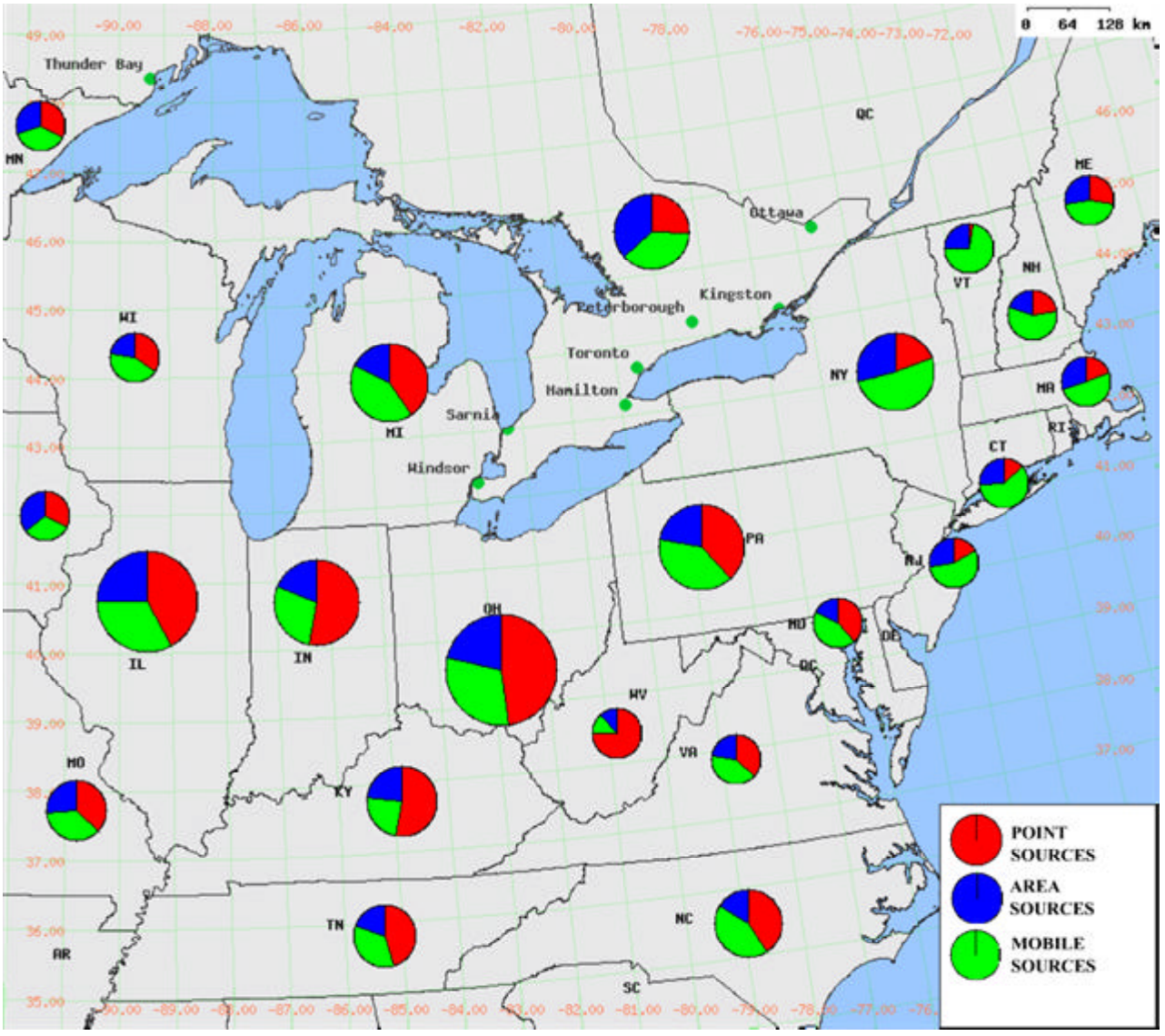


Figure 2.4: NO_x emission by source type at selected states/province.
U.S. 1999 and Canada 2000 emission inventories.
Pie diameter is proportional to emission scale.
(source: Ontario Ministry of the Environment)

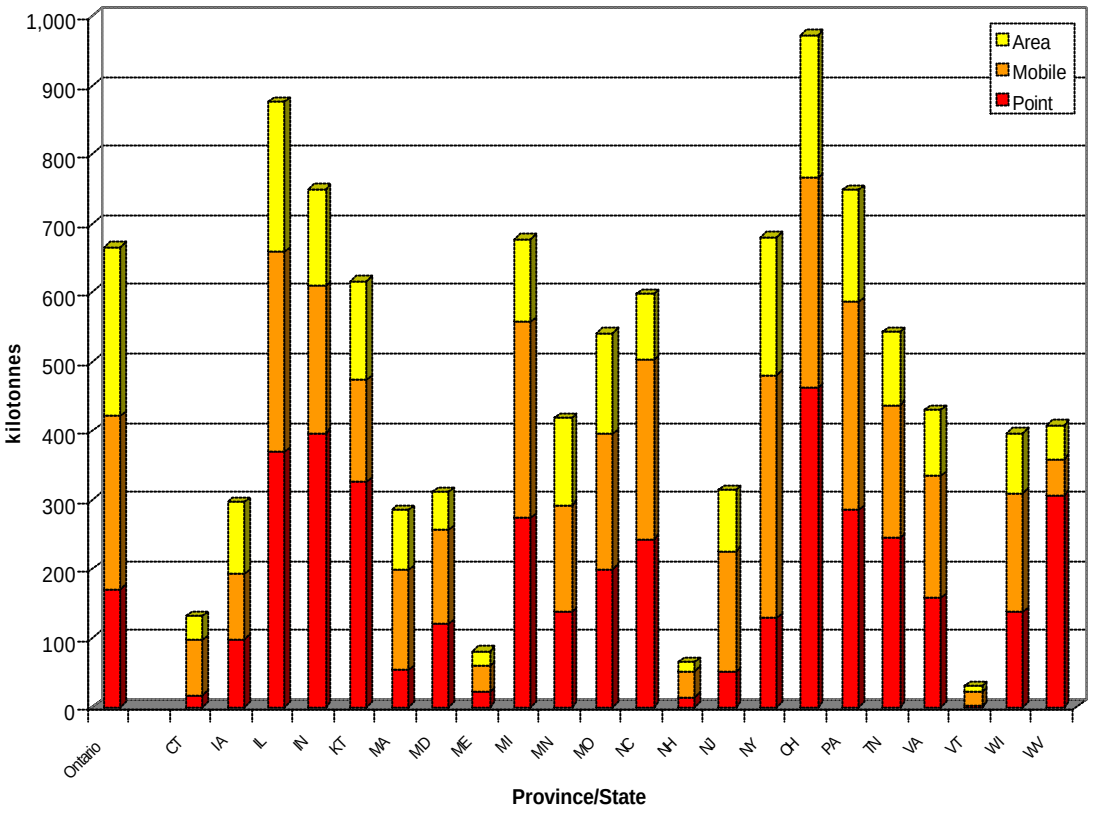


Figure 2.5: Ontario (2000) and U.S. State (1999) NO_x Emission Estimates from Human Activity
(source: Ontario Ministry of the Environment)

Volatile Organic Compounds (VOCs)

Volatile organic compounds are emitted into the atmosphere from a variety of anthropogenic and natural sources. Some of the major anthropogenic sources include vehicles, fossil fuel combustion, steel-making, petroleum refining, fuel-refilling, industrial and residential solvent use, paint application, manufacturing of synthetic materials, food processing, agricultural activities and wood processing and wood burning. Vegetation sources are significant, and are the main contributors of natural VOC emissions. Certain VOCs[7] warrant special attention because they play an important role in the formation of ground-level ozone and fine particulate matter. VOCs that contribute to the formation of ozone typically have a short life span in the atmosphere. In contrast,

[7] Examples of VOCs include: alkanes, alkenes, aromatics and formaldehyde.

VOCs that are least reactive to ozone formation are capable of being transported very long distances as they have a long life-time in the troposphere. In 2000 the on-road transportation sector accounted for approximately 16 per cent of Ontario's emissions from human activity. Point sources made up 19 per cent and area sources accounted for the most significant portion of VOC emissions at 65 per cent. A detailed breakdown by source type and emission rates is illustrated in Figure 2.6. In the Ontario and neighbouring U.S. airshed, Ontario's VOC emissions account for approximately 7 per cent of the combined total emitted. Detailed contribution by sector for Ontario and neighbouring U.S. states is shown in Figure 2.7.

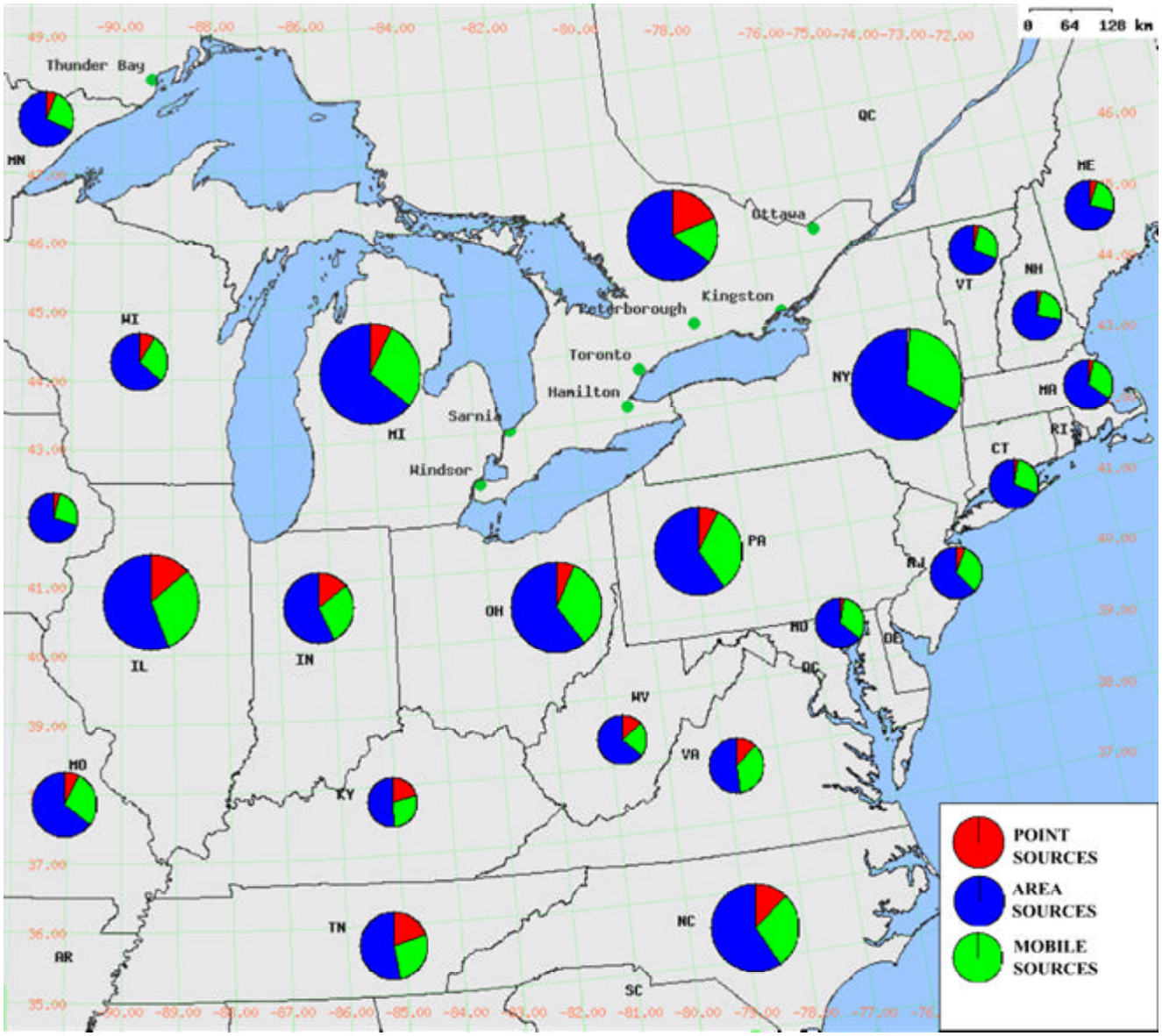


Figure 2.6: VOC emission by source type at selected State/Province.
U.S. 1999 and Canada 2000 emission inventories.
Pie diameter is proportional to emission scale.
(source: Ontario Ministry of the Environment)

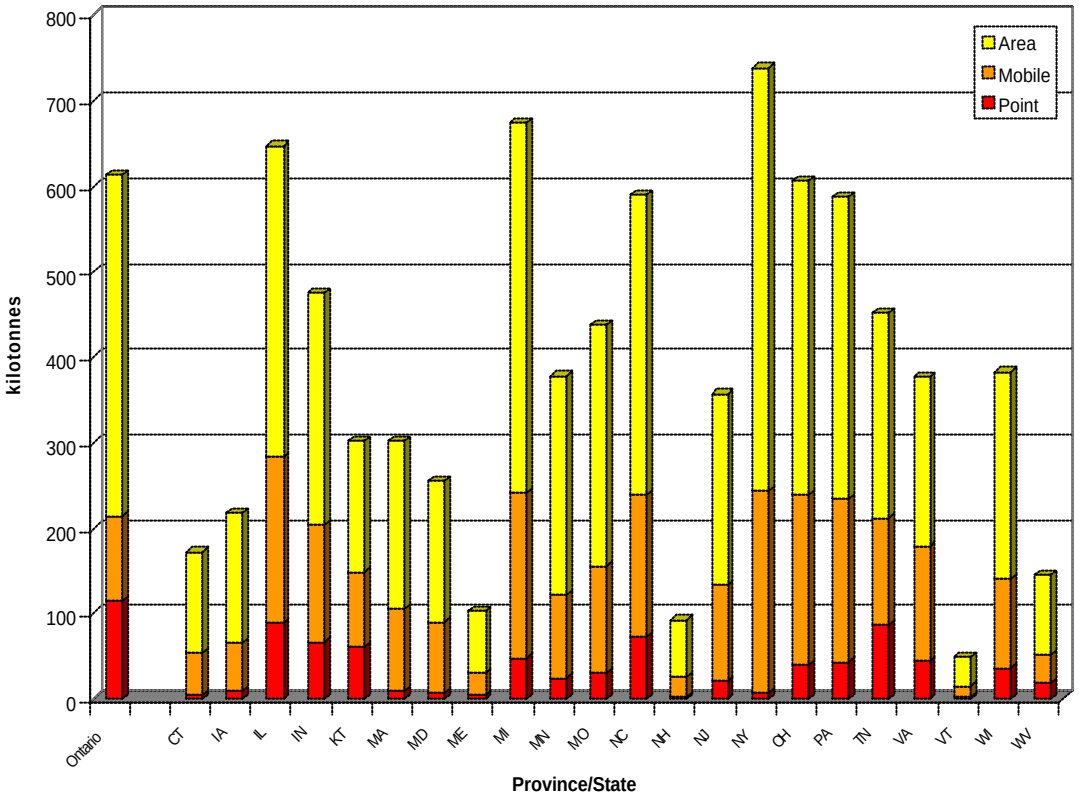


Figure 2.7: Ontario (2000) and U.S. State (1999) VOC Emission Estimates from Human Activity
(source: Ontario Ministry of the Environment)

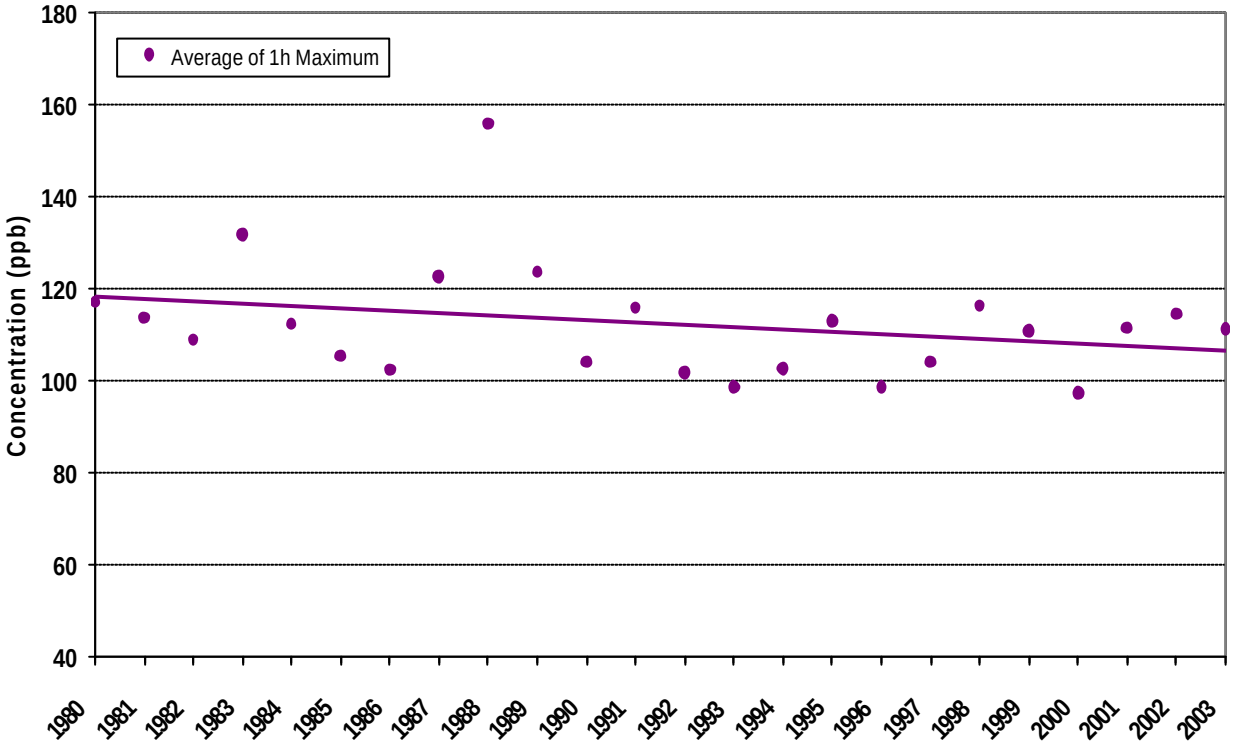
Exposure to elevated concentrations of ground-level ozone is of significant concern to all living organisms. Ozone irritates the respiratory tract and eyes. When exposed to ozone, sensitive individuals can experience chest tightness, coughing and wheezing. Children playing outdoors in the summer, when ground-level ozone levels are at their highest, are particularly at risk of experiencing such effects. Individuals with pre-existing respiratory disorders, such as asthma and chronic obstructive pulmonary disease, are also at greater risk. Ground-level ozone has been linked to increased hospital admissions and emergency room visits. It also causes visible leaf damage to crops, garden plants and trees and is responsible for agricultural crop losses each year, mostly in southwestern Ontario, although with the introduction of more ozone tolerant varieties in recent years, the economic impacts on crops is lower than it used to be.

The geographical distribution of the number of ozone exceedances across Ontario in 2003 is shown in Figure 2.8. The significance of transboundary flow is reflected in the relatively higher levels found at rural sites in the southwestern part of the province along

the northern shore of Lake Erie. An area of elevated ozone levels to the east of Toronto in the Belleville area is also evident and is attributed to the long-range transport of pollutants into Ontario from the U.S. and potential impacts from the urbanized area of the Golden Horseshoe, including the Greater Toronto Area (GTA). In general, ozone levels in southern Ontario decrease from southwest to northeast. Significant amounts of Ontario's ozone levels during widespread smog episodes are due to long-range transport of ozone and its precursors (NO_x and VOCs) from neighbouring U.S. states. This U.S. contribution, excluding background levels, is expected to be as much as 90 per cent in Ontario cities and towns on the northern shore of Lake Erie including Port Stanley and Simcoe, the eastern shores of Lake Huron and Georgian Bay such as Parry Sound, and in the extreme southwest near the U.S. border such as Windsor.

Figure 2.8: Geographical Distribution of Number of One-Hour Ozone Exceedances Across Ontario (2003)
(source: Ontario Ministry of the Environment)

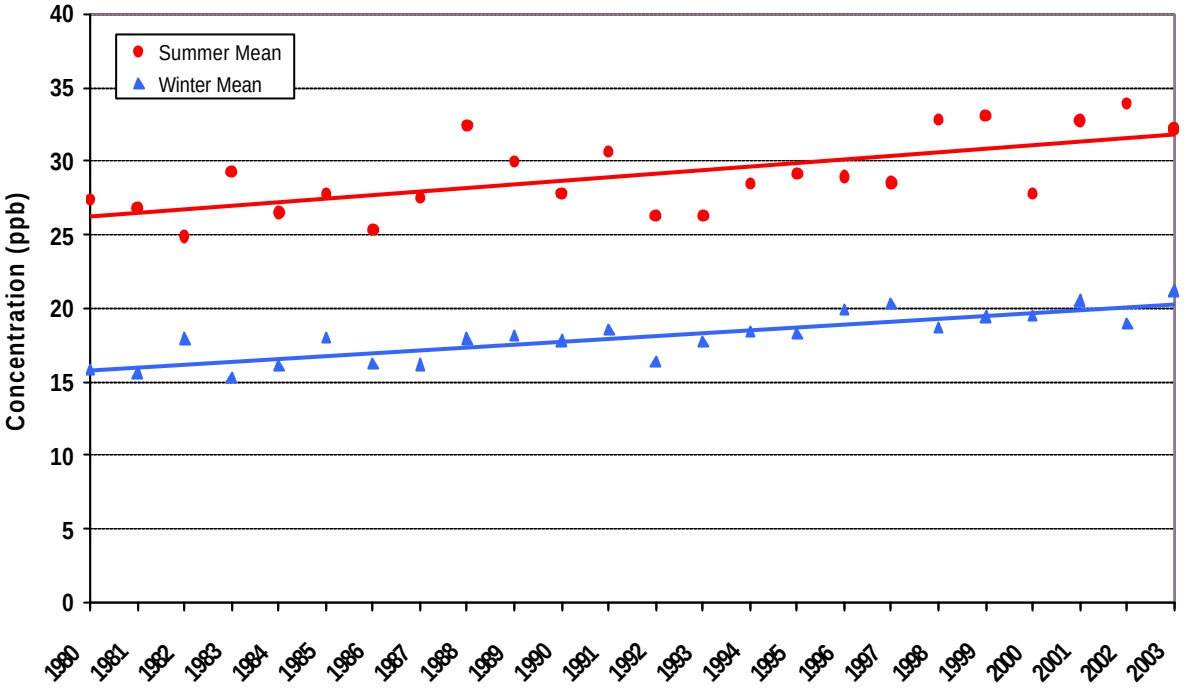
In terms of ground-level ozone trends, data from the period 1980 to 2003 show evidence of a slowly declining trend in the ozone one-hour maximum concentrations in Ontario (Figure 2.9). Over the same 24–year period, the trend of the ozone seasonal means (summer and winter) reveals increasing trends (Figure 2.10). The ozone summer means have increased by about 21 per cent and the winter means by about 29 per cent. The increases in summer and winter ozone means are largely related to rising global background concentrations of ozone throughout Ontario. This increase in background concentrations of ozone observed throughout Ontario is similarly found in other areas of Canada and across North America[8]. Additional contributions to the increases in the summer may be related to meteorological factors and long-range transport of ozone and its precursors from the U.S.



Note: Based on data from 17 ozone sites operated over 24 years.
Ontario 1h AAQC = 80 ppb.

Figure 2.9: Trend of Ozone One-Hour Maximum Concentrations in Ontario (1980- 2003) (source: Ontario Ministry of the Environment)

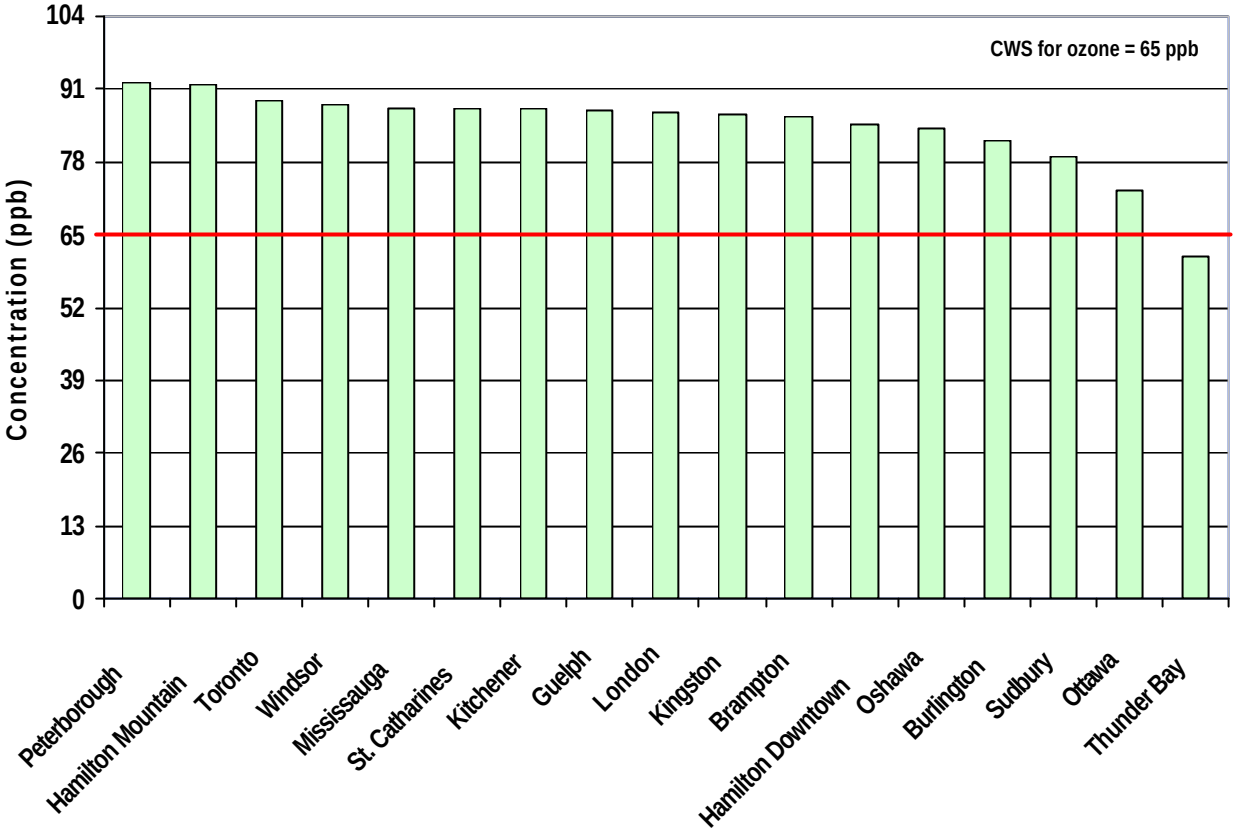
[8] Lin, C.C-Y., Jacob, D.J., Munger, J.W., and A.M. Fiore. 2000. Increasing background ozone in surface air over the U.S. *Geophysical Research Letters,* Vol. 27(21), pp. 3465-3468.



Note: Based on data from 17 ozone sites operated over 24 years;
Seasonal definitions - Summer (May to September); Winter (January to April, October to December).

Figure 2.10: Trend of Ozone Seasonal Means at Sites Across Ontario (1980- 2003)
(source: Ontario Ministry of the Environment)

The current ozone measurements in Ontario with respect to the Canada-wide Standard (65 parts per billion, 8-hour running average time, based on the 4th highest annual ambient measurement averaged over three consecutive years) are shown for the period 2001-2003 in Figure 2.11. This shows that ozone concentrations at selected sites exceeded the CWS standard at all but one site, Thunder Bay, which is located in northwestern Ontario on the northern shore of Lake Superior.



Note: Displayed sites are selected based on future requirements for Canada-wide Standard (CWS) reporting. Toronto reporting is based on Toronto Downtown, Toronto North, Toronto East and Toronto West sites.

Figure 2.11: Ozone Levels at Selected Sites Across Ontario
4th Highest Ozone 8-Hour Maximum (2001-2003)
(source: Ontario Ministry of the Environment)

Canadian provinces and territories are required to meet this new standard by 2010, with comprehensive reporting on progress toward meeting the standard, beginning in 2006. Ontario is on track in meeting this reporting target. Transboundary air pollution flow must be considered in that reporting. Although the analysis indicates that neighbouring U.S. states are significant contributors to elevated ozone levels in certain areas of Ontario, the determination of the relative contributions of transboundary movement of ozone and its precursors into and out of the province needs further assessment. Towards this end, and to quantify the transboundary versus local components of observed ozone levels in Ontario, concurrent use of air quality modelling have been undertaken and are presented in the next chapter.

2.2 Fine Particulate Matter ($PM_{2.5}$)

Airborne particulate matter is the general term used to describe a mixture of microscopic solid particles suspended in air. Particulate matter is characterized according to its size – mainly because of the different health effects associated with particles of different diameters. Fine particulate matter or respirable particles refer to particles that are 2.5 microns in diameter and less, that may penetrate deep into the respiratory system.

Particles originate from many different industrial and transportation sources, as well as from natural sources. They may be emitted directly from a source or formed in the atmosphere by the transformation of gaseous emissions; similar to ground-level ozone. A detailed breakdown by source type and emission rates is illustrated in Figure 2.12. Area sources make up the most significant portion of anthropogenic $PM_{2.5}$ emissions in both Ontario and neighbouring U.S. states as reflected in Figure 2.13. Neighbouring U.S. states, as a whole, release approximately 28 times as much primary $PM_{2.5}$ emissions as does Ontario based on area, on-road transportation and point sources.

Particulate matter includes aerosols, smoke, fumes, dust, fly ash and pollen. Its composition varies with origin, residence time in the atmosphere, time of year and environmental conditions. Fine particulate matter may also be formed indirectly through a series of complex chemical reactions in the atmosphere and directly through fossil fuel combustion, such as motor vehicles, power generation, industrial facilities, residential gas fireplaces, as well as wood combustion in stoves and fireplaces, agricultural burning, forest fires and natural phenomena such as volcanoes and sea salts.

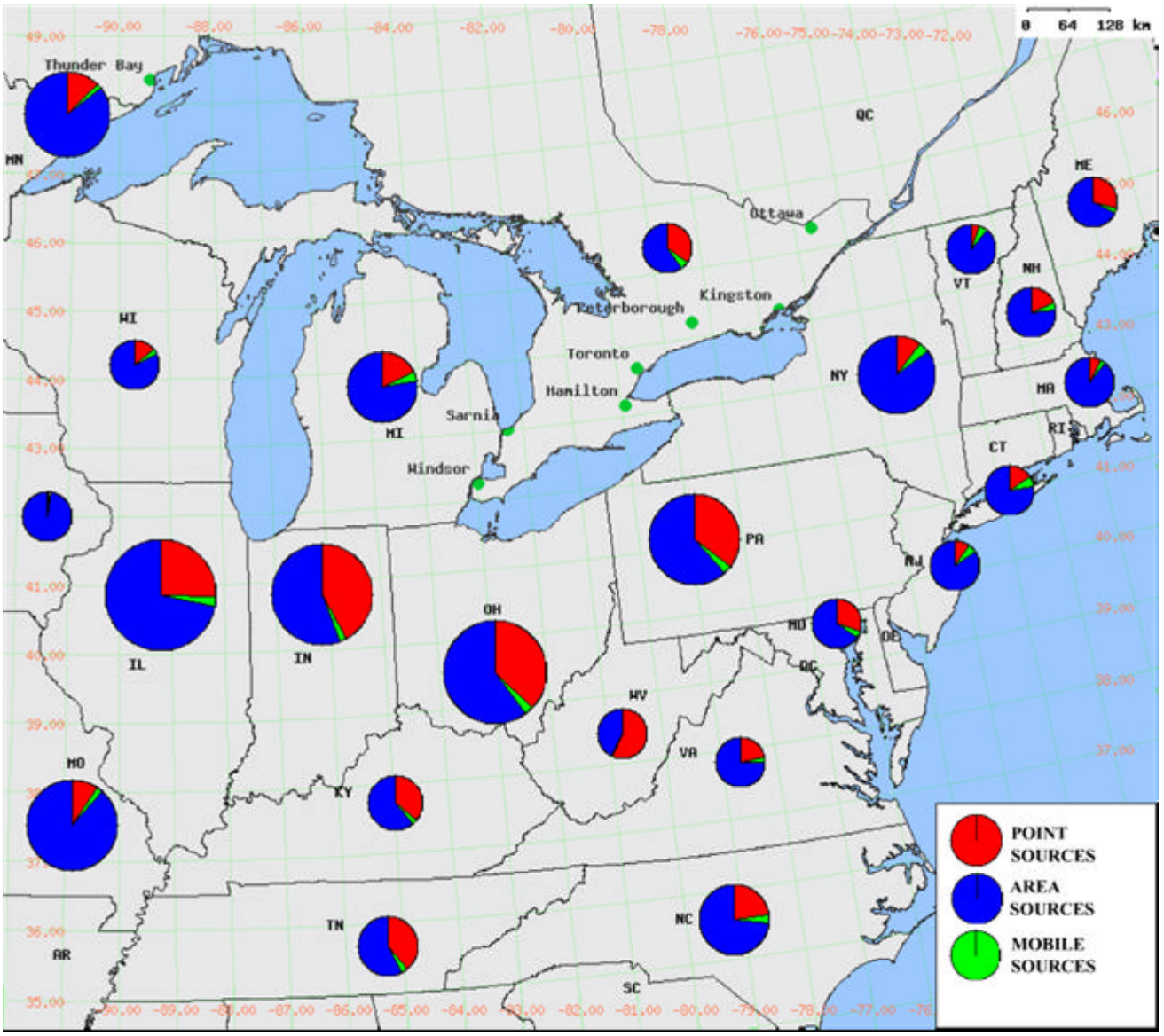


Figure 2.12: $PM_{2.5}$ emission by source type at selected State/Province.
U.S. 1999 and Canada 2000 emission inventories.
Pie diameter is proportional to emission scale.
(source: Ontario Ministry of the Environment)

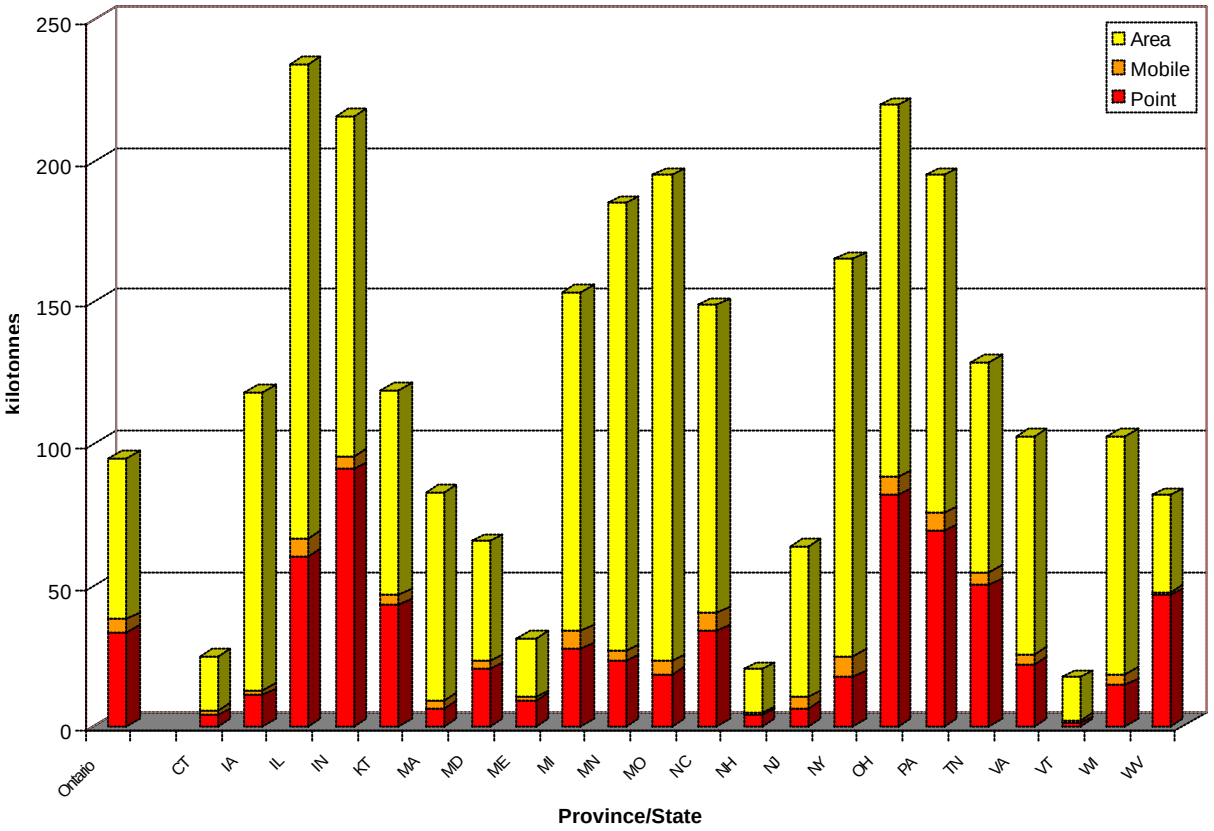


Figure 2.13: Ontario (2000) and U.S. State (1999) $PM_{2.5}$ Emission Estimates from Human Activity

(source: Ontario Ministry of the Environment)

Significant amounts of $PM_{2.5}$ measured in southern Ontario are of transboundary origin. During periods of elevated levels of $PM_{2.5}$ in Ontario, it is estimated that there are very significant contributions from the U.S., specifically in border cities and towns including Windsor and Parry Sound. The quantification of transboundary versus local sources to $PM_{2.5}$ levels in Ontario will be presented in the model assessment in Chapter 3. Exposure to $PM_{2.5}$ is associated with hospital admissions, a number of serious health effects, and premature death. [9] People with asthma, cardiovascular or lung disease, as well as children and the elderly are considered to be most at risk. Adverse health effects have been associated with exposure to higher levels of $PM_{2.5}$ over short periods of time (a single day) and to low chronic doses over longer periods of a year or more. Fine particulate matter may also be responsible for environmental impacts such as reduced visibility, corrosion and damage to vegetation and sensitive aquatic ecosystems.

[9] Ontario Medical Association. *The illness costs of air pollution in Ontario: a summary of findings*. July 2000.

Like ground-level ozone, $PM_{2.5}$ can be transported many hundreds of kilometres from its point of origin. For example, during the northern Quebec forest fires in July 2002 vast areas of eastern North America, including parts of southern Ontario, were impacted, as far as 900 km south of the fires. Twenty-four hour average $PM_{2.5}$ concentrations over 70 $\mu g/m^3$ were recorded at the Peterborough and Ottawa air monitoring locations. Air quality readings of $PM_{2.5}$ during this episode were at "record levels" at a number of sites across southern and eastern Ontario, including the Greater Toronto Area, Peterborough and Ottawa[10].

Preliminary analysis of $PM_{2.5}$ measurements in Ontario indicate that during summertime episodic conditions, both ozone and fine particulate matter are elevated, and invariably days with high levels of $PM_{2.5}$ are subsets of the elevated ozone level days. The onset of high $PM_{2.5}$ days often lagged elevated ozone days with aging in the air mass (Figure 2.14).

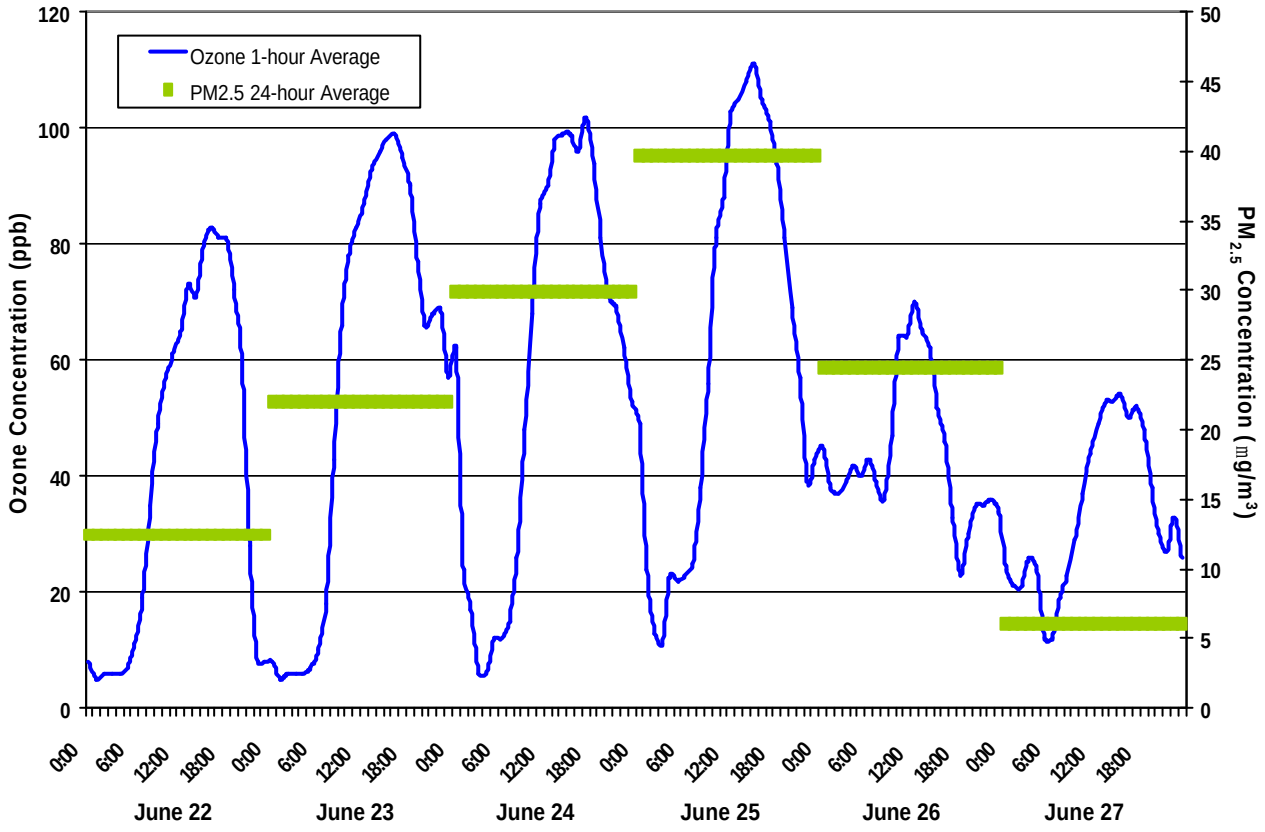
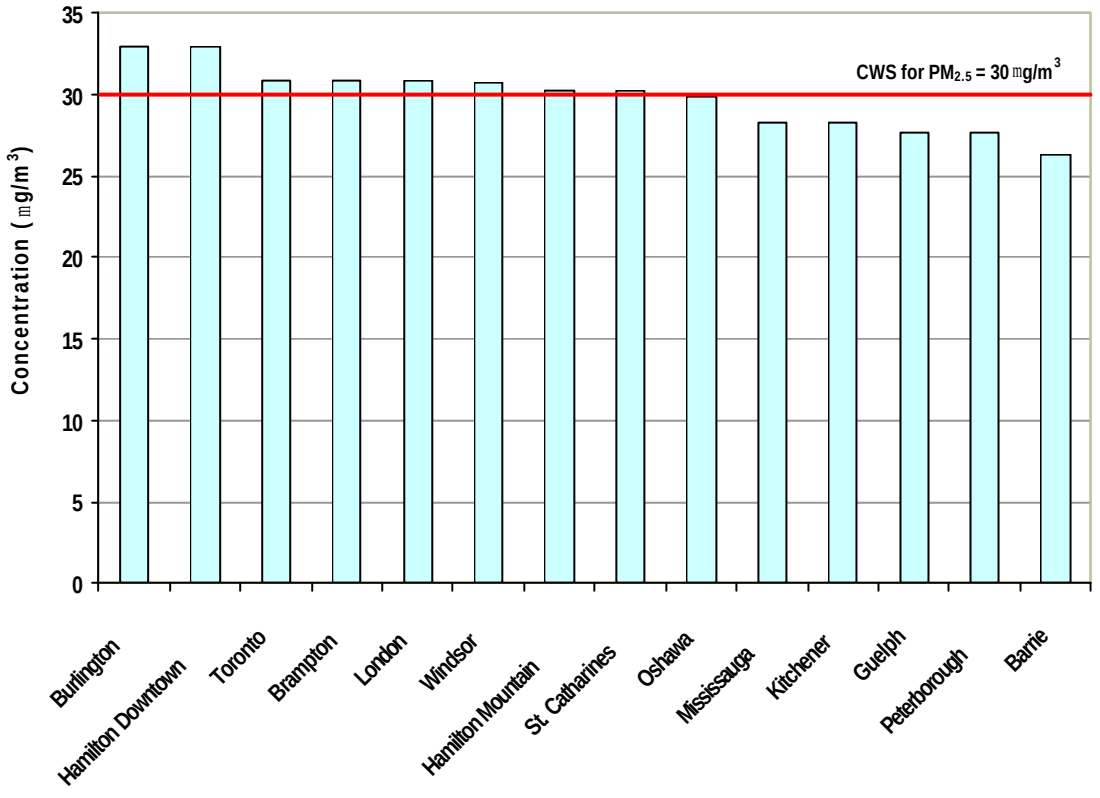


Figure 2.14: One-Hour Average Ozone Concentrations and 24-Hour Average $PM_{2.5}$ Concentrations in Windsor During June 2003 Episode
(source: Ontario Ministry of the Environment)

[10] Air Quality in Ontario 2003 Report, Ontario Ministry of the Environment, Queen's Printer for Ontario, 2004.

During the winter, $PM_{2.5}$ smog episodes are significantly less frequent, and are more related to a combination of factors including transboundary transport, near stagnant weather conditions and local build-up of pollutants.

The current fine particulate measurements and their relationship to the Canada-wide Standard (30 µg/m^3, 24-hour averaging time, 98th percentile annually, averaged over 3 consecutive years) are shown for the years 2001-2003 at various sites across Ontario in Figure 2.15. Like ozone, the highest levels are seen in the more southerly parts of the province reflecting the strong transboundary influence in those areas. Areas that exceeded the CWS for fine particulate matter were confined to southwest Ontario and the Golden Horseshoe, including that of the GTA. The higher levels in the more urbanized areas suggest added contributions from Ontario sources also play a role. As with ground-level ozone, new air modelling assessments have been undertaken to assess and quantify various source contributions to observed levels.



Note: PM_{25} concentrations are measured by TEOM (Tapered Element Oscillating Microbalance);
Displayed sites are selected based on future requirements for Canada-wide Standard (CWS) reporting.

Figure 2.15: $PM_{2.5}$ Levels at Selected Sites Across Ontario
98th Percentile $PM_{2.5}$ Daily Average (2001 - 2003)
(source: Ontario Ministry of the Environment)

2.3 Smog Episodes and Meteorology

Numerous researchers have studied the generation, build-up and dissipation of air pollutant concentrations over eastern North America over the past three decades. Such studies have shown that the air pollutant life cycle is strongly influenced by weather systems in the order of thousands of kilometres. In particular, pollutants associated with various air issues such as acid species, ground-level ozone and its precursors, fine particles, and hazardous air pollutants, are often transported by large-scale weather systems up to thousands of kilometres from their point of origin before being deposited or impacting on receptors.

For southern Ontario, episodes of elevated ground-level ozone usually occur over the summer months and are associated with high pressure weather systems that typically move out of central Canada into the mid-west of the U.S. or the Great Lakes area and then eastward to the Atlantic coast. The "back of the high" (see Figure 2.16) portion of a slow moving high pressure area generally has winds with a southerly component that have travelled over major precursor source areas located in the mid-west and eastern United States. As the high pressure moves from west to east, precursors are emitted into the front of the system and circulate to the rear of the system over a period of 2 to 6 days depending on the wind speed. This results in the accumulation of a number of pollutants (both primary and secondary species) in the air mass. As a result, south to southwesterly flow on the rear side of a high pressure system provides favourable conditions for transport of pollution and is conducive for episodes of fine particles and ozone pollution simultaneously over southern Ontario.

Figure 2.16 illustrates a generalized summer synoptic weather pattern over southern Ontario during elevated smog conditions. This results in the long-range transport of smog pollutants, specifically ozone and fine particulate matter, during warm, south to southwesterly air flow conditions.

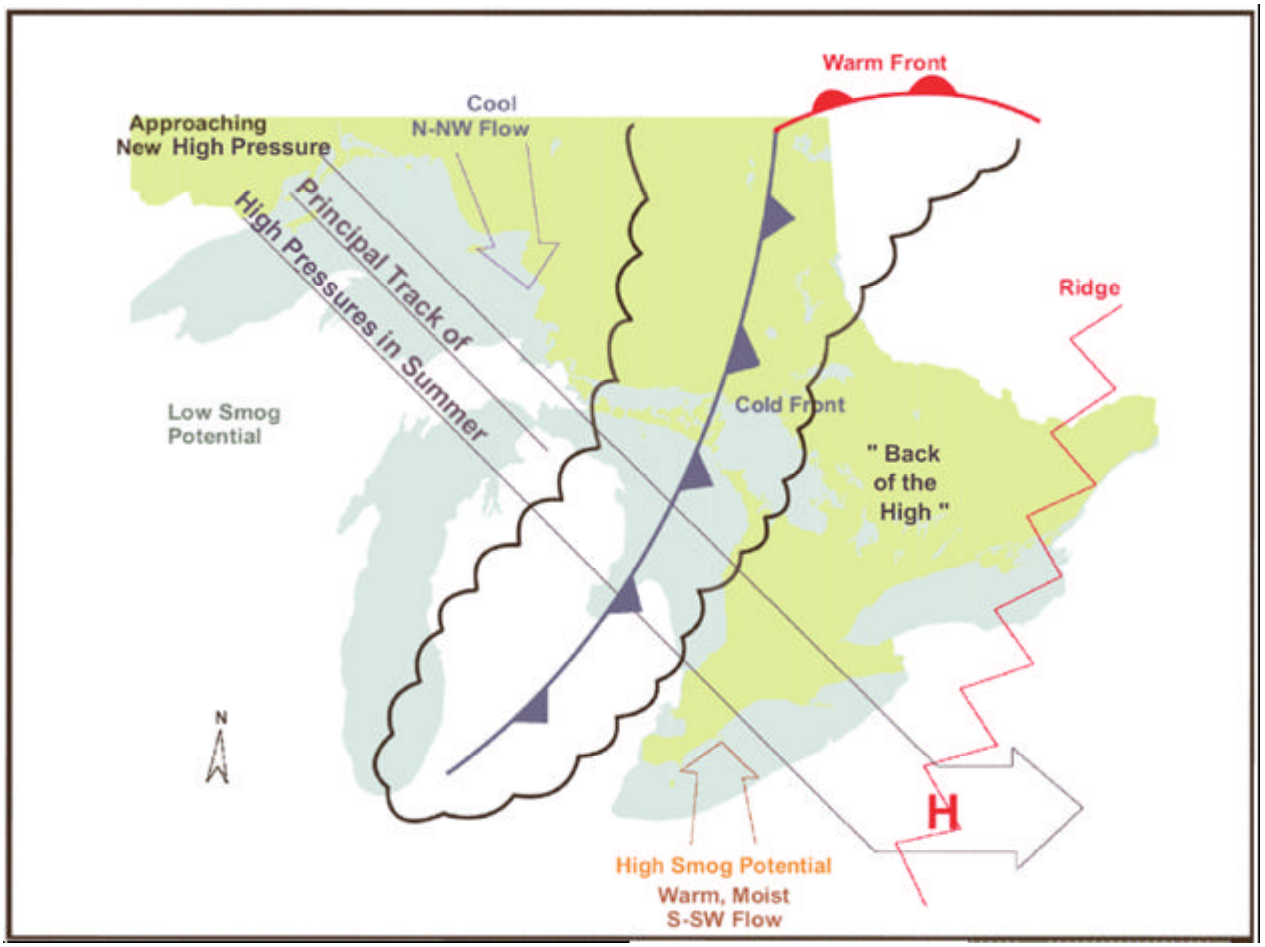


Figure 2.16: Generalized Synoptic Weather Pattern Over Southern Ontario Conducive to Elevated Pollutant Levels
(source: Ontario Ministry of the Environment)

Summer smog episodes in Ontario are often a part of a regional weather condition that prevails over much of northeastern North America. Elevated levels of ozone and fine particulate matter are typically associated with weather patterns that affect the lower Great Lakes region. Such weather patterns are invariably associated with slow moving high pressure cells across the region and result in the long-range transport of smog pollutants into Ontario from neighbouring U.S. industrial and urbanized states including the American Mid-West and Ohio River Valley regions, during warm south to southwesterly air flow conditions. The occurrence of elevated smog levels varies from year to year in response to changes in the weather. Smog episodes over southern Ontario often reflect the northern extent of a larger regional scale smog conditions that prevail over much of northeastern North America (Figure 2.17 and 2.18).

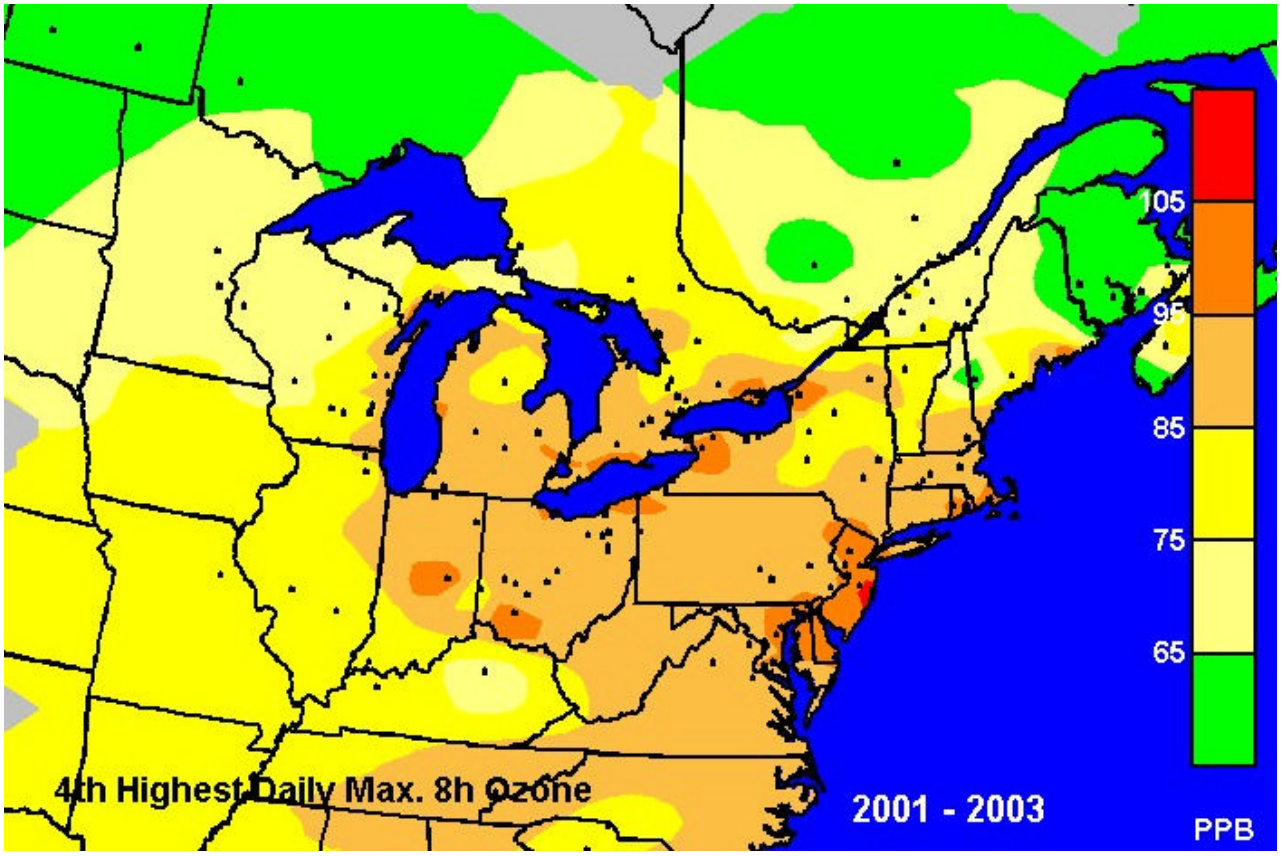


Figure 2.17: Canada-wide Standard - 4th Highest Daily Maximum 8-Hour Ozone Concentrations (2001-2003)
(source: Environment Canada 2005)

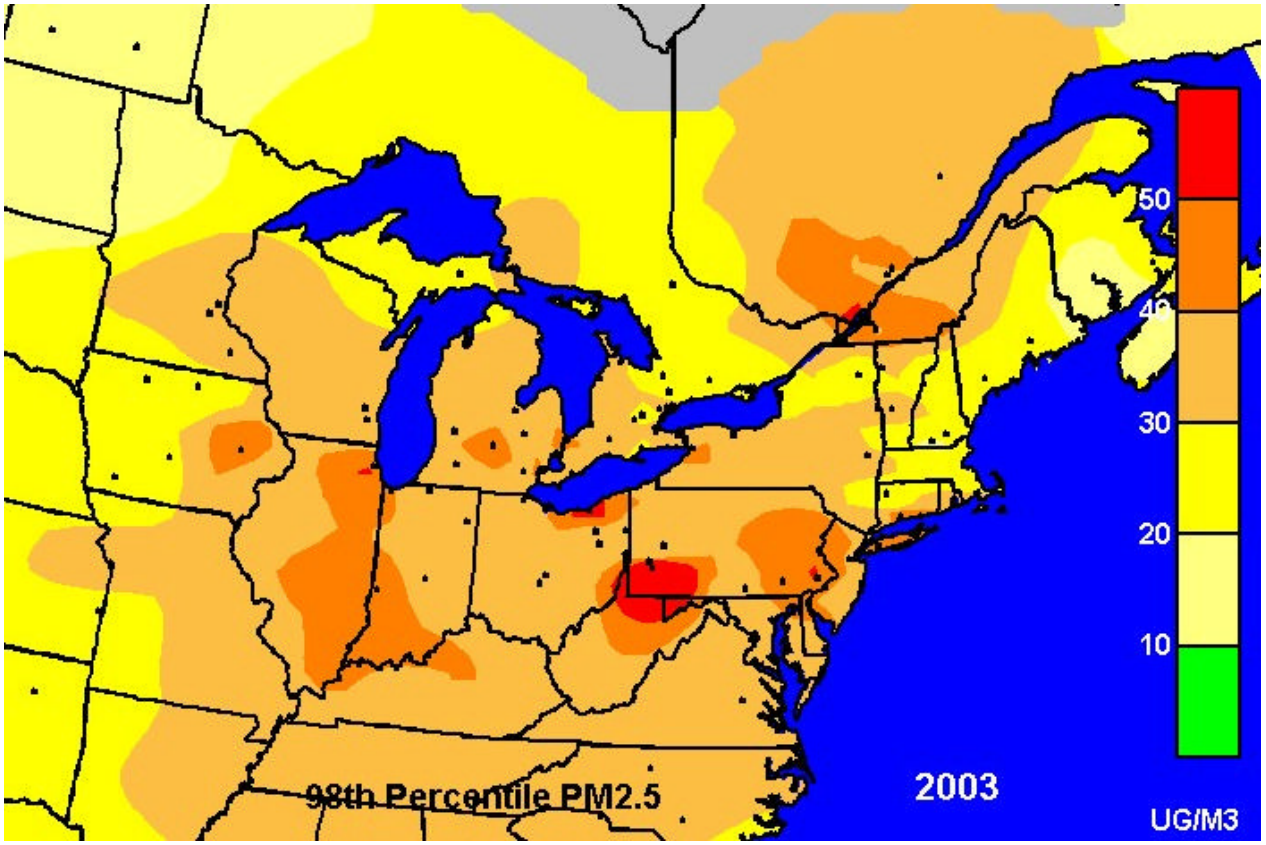
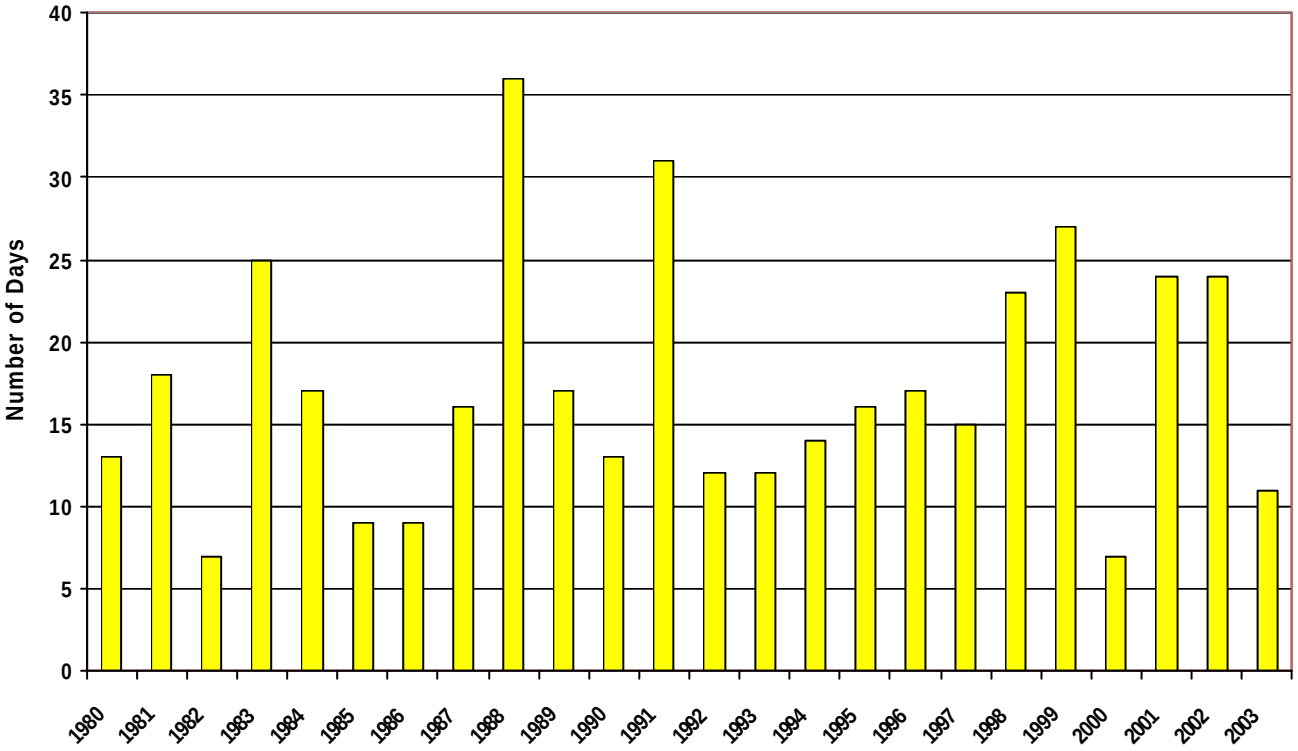


Figure 2.18: Canada-wide Standard – 98th Percentile Daily $PM_{2.5}$ Concentrations (2003) (source: Environment Canada 2005)

An example of one of the more persistent and widespread smog events in Ontario occurred during the period June 22 and 26, 2003 (see Figure 2.14). Hot, sunny conditions with light southerly winds allowed polluted air to invade the province in the extreme southwestern regions on June 22. The hot, muggy and polluted air expanded across the Greater Toronto Area the following day and persisted for the next three days over southern and eastern Ontario. Relief came on the night of June 26, 2003 as a cold front moved across impacted areas, bringing clouds and showers, which resulted in cleaner air. The strong association between $PM_{2.5}$ and ground-level ozone during the episode was apparent. The provincial one-hour ozone criterion of 80 ppb was exceeded on the first four days of the episode in Windsor. As the air mass aged, fine particulate matter concentrations gradually increased each day and exceeded the $PM_{2.5}$ reference level of 30 $\mu g/m^3$ for a 24-hour period (based on the CWS) on June 24 and 25, 2003.

Smog episodes are highly dependent upon weather conditions, which vary from year to year. To depict the trend in Ontario, the number of ozone "episode days" (days with widespread ozone levels greater than the 1-hour Ontario ozone AAQC of 80 ppb) have

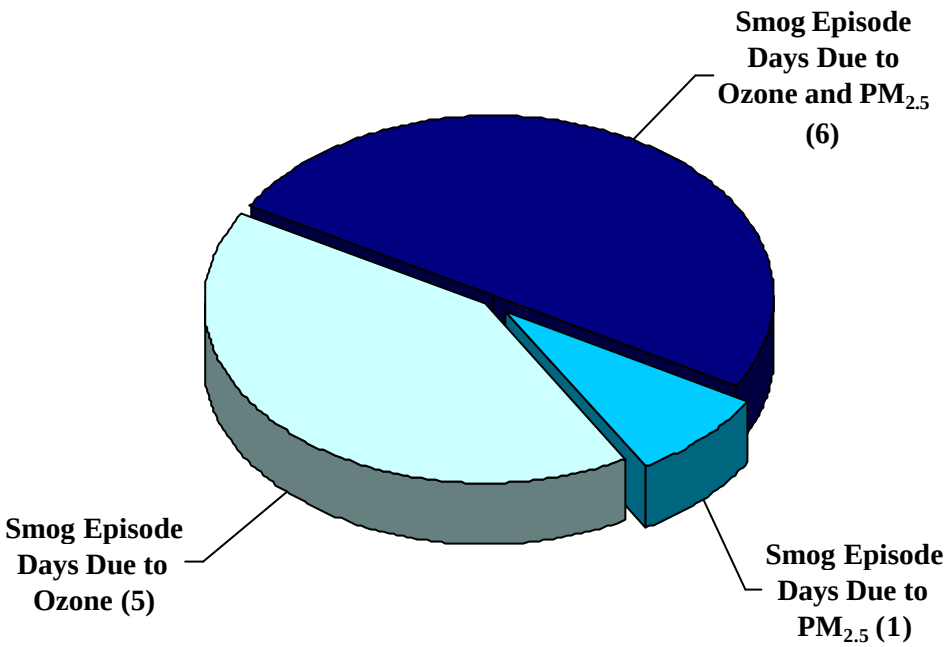
been assembled for the period 1980 to 2003 (Figure 2.19). Ozone episode days were highest in 1983, 1988, 1991, 1998, 1999, 2001 and 2002, which had relatively hot and dry summers whereas the lowest number of ozone episode days occurred in 1982 and 2000, when summers were relatively cool and wet. The air flow into Ontario on ozone episode days during summer 2003 is depicted in Figure 2.20. This qualitatively confirms the fact that summer ozone episode days are associated with flows from the heavily industrialized and urbanized regions upwind of southern Ontario. For summer 2003, there were a total of 12 smog "episode" days (Figure 2.21), 11 of which had elevated ozone levels and 7 of which had elevated fine particulate matter levels (6 of which occurred when ozone levels were also elevated).



**Ozone "episode days" defined as days with widespread ozone levels greater than the 1 -hour Ontario ozone AAQC of 80 ppb.*

Figure 2.19: Number of Ozone "Episode Days*" in Ontario (1980 – 2003)
(source: Ontario Ministry of the Environment)

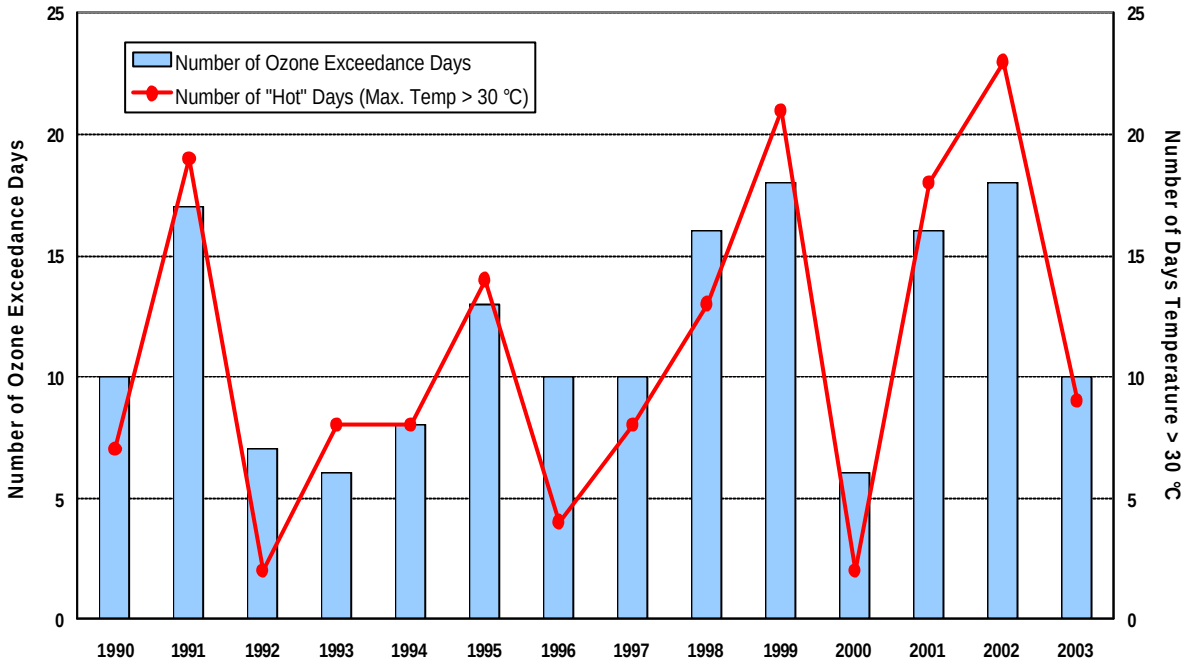
Figure 2.20: 48-hour Back Trajectories at 500mb Arriving at London, Ontario at 1300 EDT on Smog Episode Days in 2003 (source: Ontario Ministry of the Environment)



**Smog episode day due to ozone has at least 1 hour greater than the Ontario ozone AAQC of 80 ppb.*
Smog episode day due to $PM_{2.5}$ has at least 3 hour average greater than the Ontario $PM_{2.5}$ guideline of 45 mg/m^3.

Figure 2.21: Smog Episode Days in Ontario (2003)
(source: Ontario Ministry of the Environment)

Figure 2.22 provides another way of examining the ozone episode trends in Ontario. It shows the distribution of the province-wide ozone exceedance days (at least one hour greater than 80 ppb) and the number of hot days (those days with maximum temperatures greater than 30^{o}C) from1990 to 2003. The high number of ozone exceedance days in 1991, 1998, 1999, 2001 and 2002 can be largely attributed to the relatively high number of "hot" days, which are favourable to the formation and transport of ozone, whereas the low numbers of exceedance days in 2000 reflect conditions less conducive to the production of ground-level ozone.



Note: Based on 21 ozone sites operated over 14 years;
"Hot" days based on eight meteorological sites operated over 14 years;
An ozone exceedance day has at least one hour > 80 ppb.

Figure 2.22: Trend for Ozone Exeedance Days and 'Hot' Days in Ontario (1990-2003) (source: Ontario Ministry of the Environment)

Weather plays a dominant role in year-to-year variation in smog episodes in Ontario. As a consequence, there are no apparent long term trends in elevated regional ozone levels in Ontario over the past two decades.

2.4 Particulate Sulphate

Sulphate-bearing particles are amongst the most troublesome forms of particulate matter, both from the perspective of their threat to human health and through their ability to reduce visibility. Sulphate is formed when SO_2 undergoes chemical reactions in the gas phase or in cloud water[11]. In the atmosphere, ammonia is a significant precursor gas of smog yielding ammonium sulphate and nitrate species. Ammonium sulphate is a key component of fine particulate matter in summer. While all fine particles and several gaseous pollutants impair visibility, ammonium sulphate is usually the dominant light scattering pollutant in northeastern North America.

[11] Droplets of water in clouds. These water droplets in clouds are the starting point for the formation of precipitation.

Measurements of sulphate particles, both in the $PM_{2.5}$ and PM_{10}[12] size fractions, by the ministry's air monitoring network in Ontario urban air reveal that mean sulphate concentrations have decreased over the past decade, with more significant decreases in the early 1990s. This temporal trend parallels, to some extent, the sulphur dioxide decreasing trends noted in Ontario over the same time period (see Figure 2.1). Moreover, results indicate that levels of sulphate particulate matter were consistently higher in the south when compared to levels in more northern areas. Sulphate concentrations in air measured at background non-urban sites in Ontario, as part of the Canadian Air and Precipitation Monitoring Network (CAPMon) for the period 1989 to 2003 also show that sulphate levels at southern Ontario sites (Longwoods and Egbert) were consistently higher, by approximately, 1 to 2.5 $\mu g/m^3$, than at the more northern sites (Chalk River and Algoma). In addition, the annual sulphate averages in air were observed to decrease with time. In comparing the 1989 results with those recorded in 2003, the decline ranged from 30 to 40 per cent. These data provide strong evidence of a geographical gradient in sulphate concentrations across the province, with the highest concentrations measured at the southern sites. They also lend further support to the significance of the contribution of transboundary flow from U.S. sources to the levels of fine particulate and its constituents, such as sulphates, in Ontario.

A similar trend is also observed in the eastern U.S. (Figure 2.23). From 1990 to 2002, the annual average sulphate concentration measured at 34 sites in the eastern U.S. decreased by about 23 per cent. The decline is reported to be less than the corresponding decline in SO_2 concentrations. In comparing the differences between the three-year mean sulphate concentrations (1990-1992 versus 1999-2001), the largest decreases were observed along the Ohio River Valley from Illinois to Pennsylvania (Figure 2.24). The decline in particulate sulphate concentrations (Figure 2.23) was observed to track closely with the reduction in SO_2 emissions from Phase 1[13] electric utility units and ambient SO_2 concentrations.

[12] PM_{10} is defined as particulate matter size of less than 10 microns in diameter, otherwise known as inhalable particles.
[13] See Clean Air Status and Trends Network (CastNET) Annual Report (2001) http://www.epa.gov/castnet/library/annual01.html

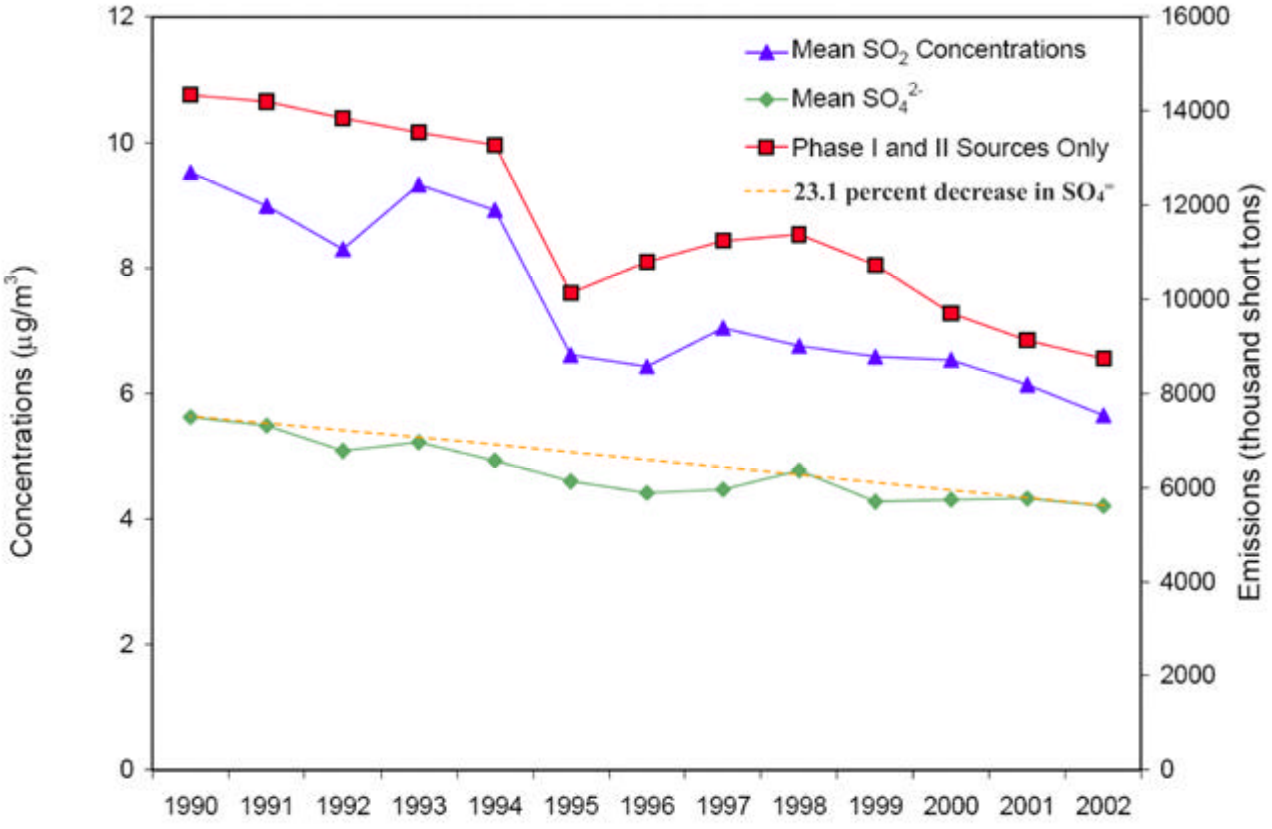


Figure 2.23: Sulphur Dioxide and Particulate Sulphate Concentrations and Electric Utility Unit Emissions (1990-2002)
(Adapted: Clean Air Status and Trends Network (CastNET) 2002 Annual Report http://www.epa.gov/castnet/library/annual02.html)

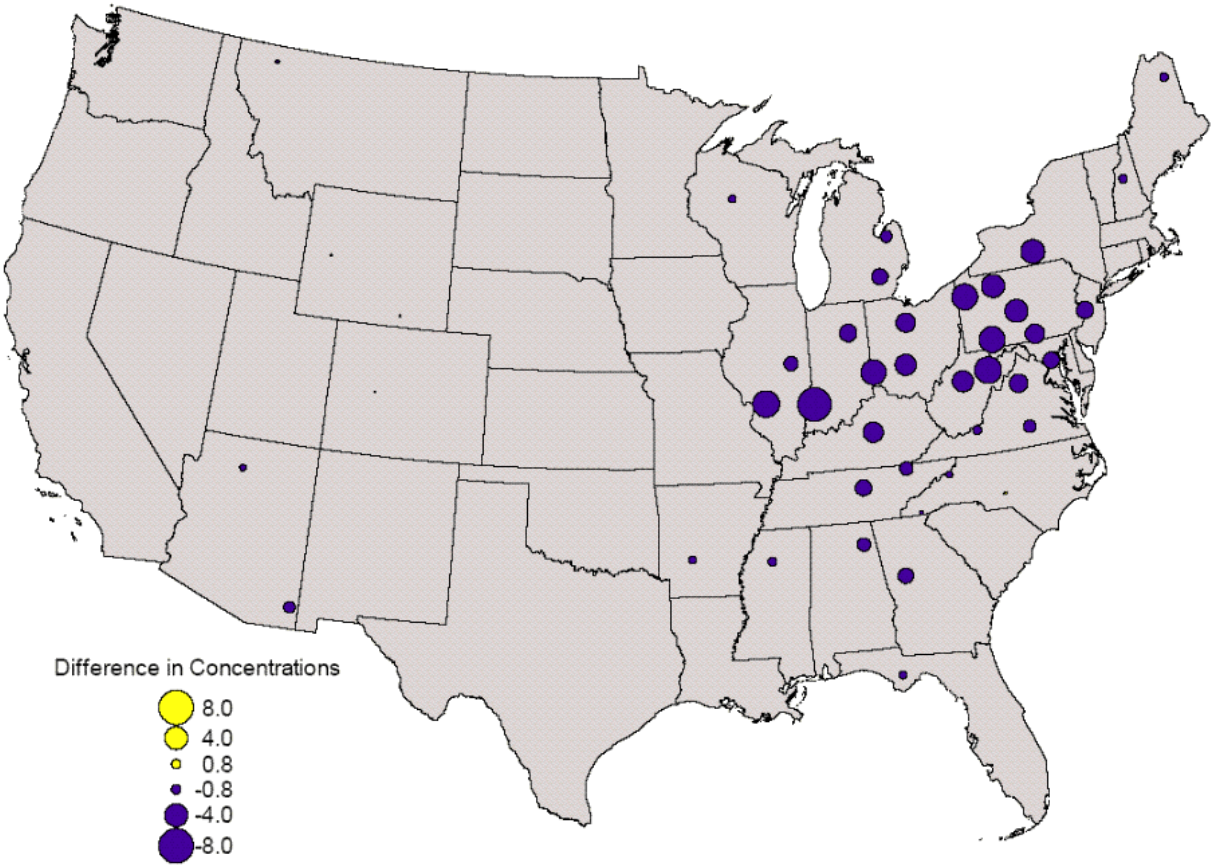


Figure 2.24: Differences Between Three-Year Mean Suphate Concentrations (1990-1992 vs. 1999-2001)
(source: Clean Air Status and Trends Network (CastNET) 2001 Annual Report http://www.epa.gov/castnet/library/annual01.html)

Hence, there is mounting evidence from ambient air quality measurements in Ontario and the eastern U.S. that reductions in SO_2 emissions have resulted in accompanying reductions in particulate sulphate concentrations. During the 1990s, Ontario SO_2 emissions declined by over 50 per cent from 1.25 to 0.6 million tonnes whereas SO_2 emissions from the Eastern U.S. (Phase I and II sources) declined by about 27 per cent. Based on U.S. (1999) and Canada (2000) emission inventories, Ontario's SO_2 emissions account for approximately 6 per cent of the combined total in the Ontario and neighbouring U.S. airshed. These findings strengthen the case for further reductions in SO_2 emissions throughout North America to reduce the levels of particulate sulphates and their associated impacts across the region including that of Ontario.

2.5 Particulate Nitrate

Nitrogen oxides are converted to nitric acid by chemical reactions in the atmosphere and can then combine with ammonia to form ammonium nitrate particles, which are typically a much smaller fraction of the fine particulate mater than ammonium sulphate. The nitric acid can also contribute to acid deposition. Particulate nitrate and nitric acid in air are measured at four CAPMoN sites in Ontario mentioned previously, Longwoods, Egbert, Chalk River and Algoma. From data collected during the period 1989 to 2003, air concentrations of nitrates (particulate nitrate + nitric acid) were about 3 $\mu g/m^3$ higher at southern sites compared to the more northerly sites. However unlike the temporal decline observed for the sulphate results, changes in the concentration of nitrate over the 15-year period were barely evident. During the 1990s, NO_x emissions declined by about 15 per cent in Ontario from 650 to 550 tonnes whereas NO_x emissions from the U.S. (Phase I and II sources) declined by 10 per cent from about 4.50 to 4.05 million tonnes.

2.6 Acidic Rain and Acid Deposition

Acid rain is a serious environmental problem that affects large parts of the U.S. and Canada. While there has been success at reducing acid-causing emissions, acid deposition is still affecting the Ontario environment, and acid aerosols the health of Ontarians. Acid rain results from the deposition of sulphuric acid and nitric acid formed when SO_2 and NO_x react in the atmosphere with oxidants such as the hydroxyl radical (Figure 2.25). As these pollutants travel across national and international borders, they are converted to sulphate and nitrate compounds and then to acid solutions. The deposition can be in the wet, as precipitation, and dry form, as particles.[14]

[14] 2004 Canadian Acid Deposition Science Assessment – Summary of Key Results. Environment Canada, released February 2005; full report available upon request.

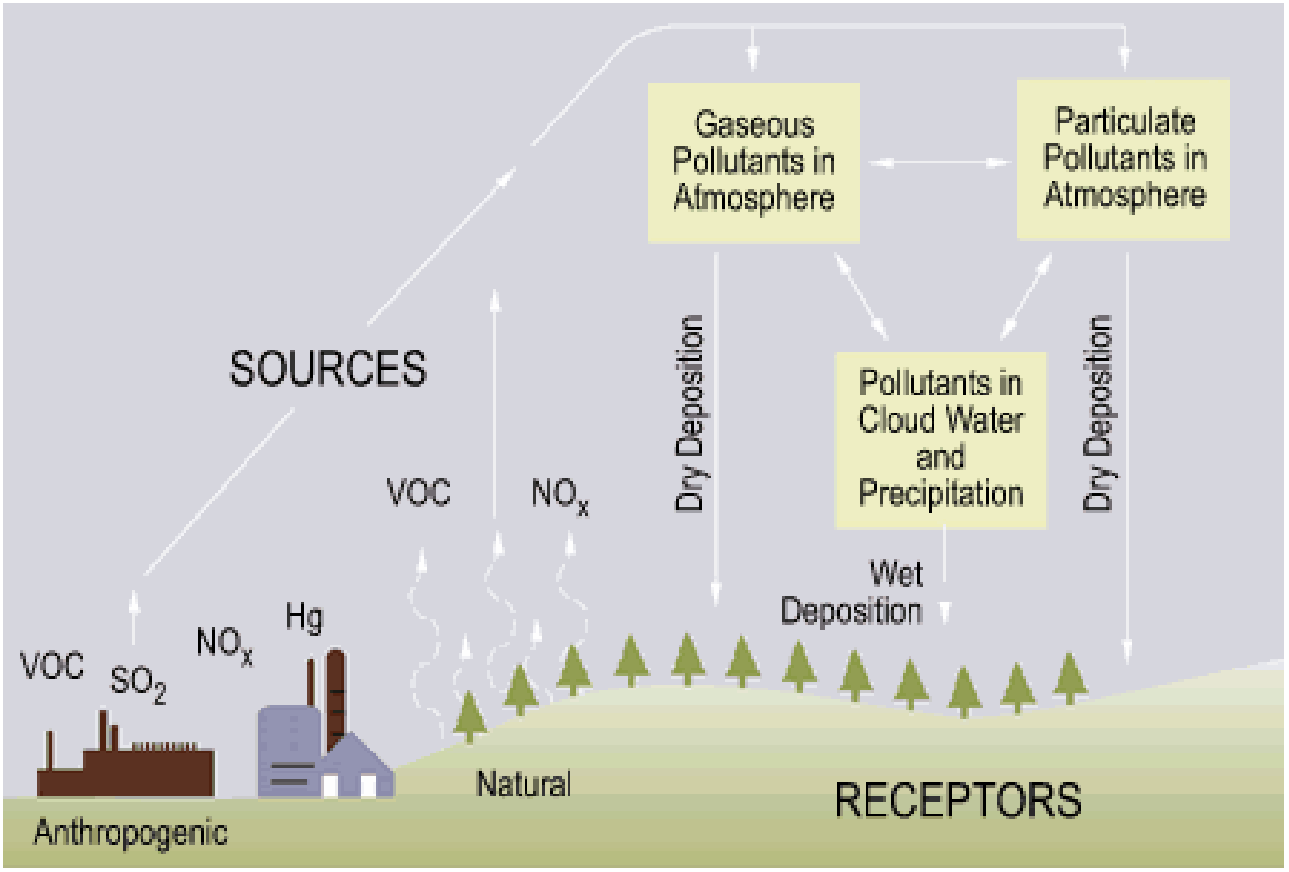


Figure 2.25: Acid rain formation and acid deposition
(source : www.epa.gov/acidrain/index.html#what)

In eastern Canada, sulphur compounds in deposition are still the predominant acidifying agent. However, there is growing concern about the nitrate component as it could result in the acidification of ecosystems in the future. Dry deposition is also of concern since, on the average, it can account for about half of the total acidic deposition. Near major sources of SO_2, such as non-ferrous smelters (e.g. Inco Limited and Falconbridge Limited), the dry sulphate component can be considerably higher than the wet component.

The adverse impacts of acid deposition are numerous and extensive: it results in acidification of sensitive lakes and streams adversely affecting biota; contributes to the damage of many sensitive soils; and accelerates the decay of building materials and paints. Acid deposition is also linked to other environmental issues such as smog and

climate change. It can also exacerbate the conversion of elemental mercury to highly toxic methyl mercury by biological activity.

Ontario has been long aware of the damaging impacts of acid deposition and the contributions from long-range transport. A major investigative study, the Sudbury Environmental Study, lasting from 1973 to 1980 indicated that, in addition to significant local sources, the Sudbury environment was affected by contributions of acid deposition from non-Sudbury sources, primarily due to long-range transport. Since that time, Ontario has aggressively pursued SO_2 emission reductions, either on its own or in concert with the federal government and the eastern provinces. In 1985, Eastern Canada's Acid Rain Program, in conjunction with Ontario's Acid Rain Program, was launched to cut SO_2 emissions in the eastern provinces in half by 1994. It was hoped that this action would reduce the wet sulphate deposition rate in eastern Canada from levels as high as 40 kg/ha/yr to less than 20 kg/ha/yr, a level that would cause considerably less damage to ecosystems. In addition, through an amendment to its Clean Air Act in 1990 and by signing the 1991 Canada-U.S. Air Quality Agreement, the U.S., by 1996, had decreased its SO_2 emissions by 27 per cent of 1980 levels.

With these decreasing emissions, the amount of acid rain has also decreased. Between 1989 and 2003, the concentration of sulphate compounds in precipitation, as measured at the four Ontario CAPMoN sites, decreased at all sites on average by about 20 per cent. From the early 1990s, the area of eastern Canada receiving more than 20 kg/ha/yr of sulphate in rain and snow had significantly declined as shown in Figure 2.26[15]. In the late 1990s central Ontario, a region particularly sensitive to acid deposition, was receiving from15 to 20 kg/ha/yr of wet sulphate deposition.

[15] 2004 Canadian Acid Deposition Science Assessment – Summary of Key Results. Environment Canada, released February 2005; full report available upon request.

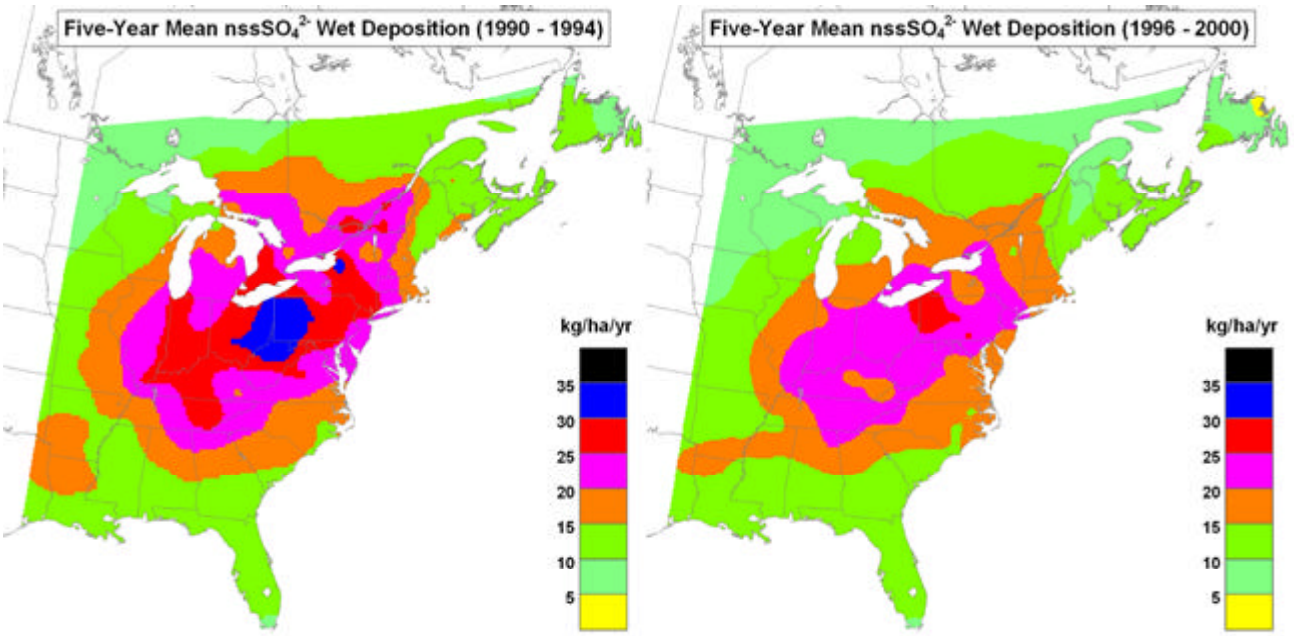


Figure 2.26: Changes to the spatial patterns of non-sea-salt-sulphate (SO_4^{2-}) wet deposition (in kg/ha/yr) in eastern North America from the early to late 1990s. The map on the left shows the 5-year-mean wet deposition pattern for the period 1990-1994 and the map on the right shows the 5-year-mean pattern for the period 1996-2000. A significant decrease in the area receiving deposition in excess of 20 kg/ha/yr has occurred in response to decreases in SO_2 emissions. In quantitative terms, the footprint area receiving equal or greater than 20 kg/ha/yr declined 76% from 1990-1994 to 1996-2000. (source: 2004 Canadian Acid Deposition Science Assessment – Summary of Key Results. Environment Canada, released February 2005; full report available upon request)

Despite this significant progress, it was recognized that more action was required to fully protect not only Ontario's but also eastern Canada's ecosystems, which were found to be more sensitive to acid rain than originally thought. For some areas of Ontario, notably on the Canadian shield, critical loads for wet sulphate deposition have been estimated to be as low as 8 to 12 kg/ha/yr, with the more sensitive areas having a critical load less than 8 kg/ha/yr.

The concentration of nitrate compounds in precipitation has not mirrored the observed declines for sulphate compounds. Since 1989, the concentration of nitrates in precipitation in Ontario has either remained unchanged or increased slightly. Areas receiving more than 20 kg/ha/yr of wet nitrate deposition show little change since the early 1990s (Figure 2.27[16]). Reducing nitrogen oxide emissions is thus of increasing importance. The contribution to acidification from current nitrate deposition, if

[16] 2004 Canadian Acid Deposition Science Assessment – Summary of Key Results. Environment Canada, released February 2005; full report available upon request.

unchanged, could eventually erode the benefits gained from the reductions in SO_2 emissions.

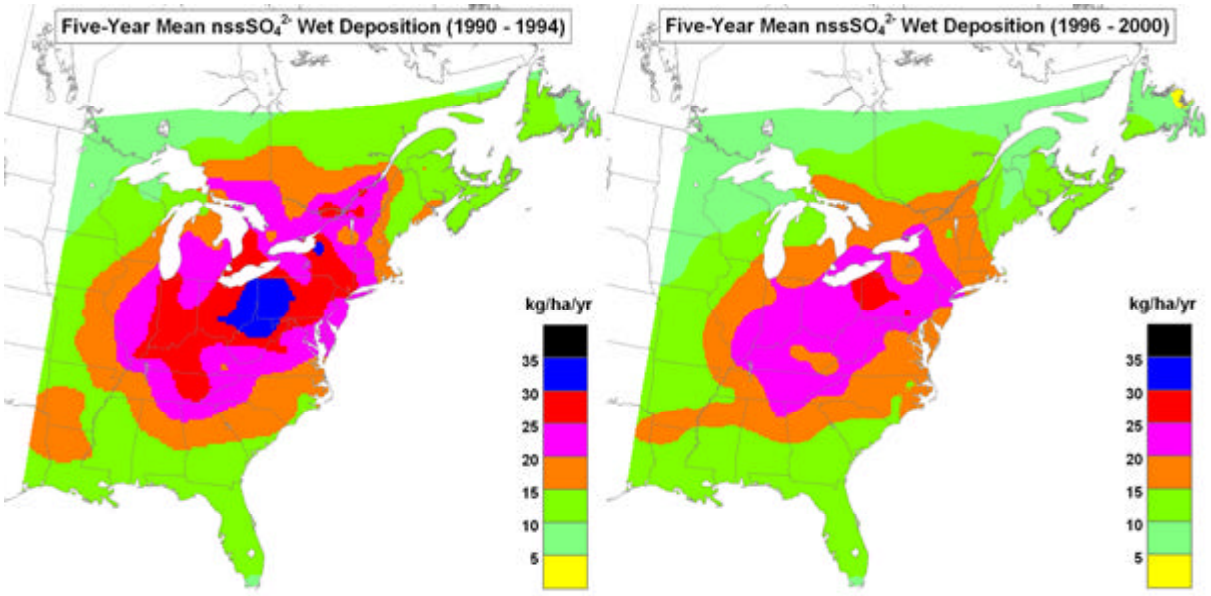


Figure 2.27: Spatial pattern of NO_3^- wet deposition over eastern North America in the early and late 1990s. The map on the left shows the 5-year-mean wet deposition pattern for the period 1990-1994 and the map on the right shows the 5-year-mean pattern for the period 1996-2000. In comparison to Figure 2.26, no major changes between the two sets of patterns are apparent; an observation that concurs with the relative constancy of NO_x emissions in this region over the same period. (source: 2004 Canadian Acid Deposition Science Assessment – Summary of Key Results. Environment Canada, released February 2005; full report available upon request)

In its 2004 Canadian Acid Deposition Science Assessment report, Environment Canada re-affirmed the significant contribution to acid deposition in eastern Canada from U.S. sources. For areas of eastern Canada and the eastern U.S. shown in the map inset of Figure 2.28, Canadian sources emit less than 10 per cent of total SO_2 and NO_x emissions in eastern North America. However, the same area of eastern Canada receives roughly 30 per cent of total sulphate and nitrate wet deposition in eastern North America. This imbalance is attributed to long-range transport and subsequent wet deposition of midwestern and eastern U.S. emissions on eastern Canada. From mass balance calculations, it is estimated that between 45 and 70 per cent of sulphate and nitrate wet deposition in eastern Canada is due to emission sources in the eastern U.S.

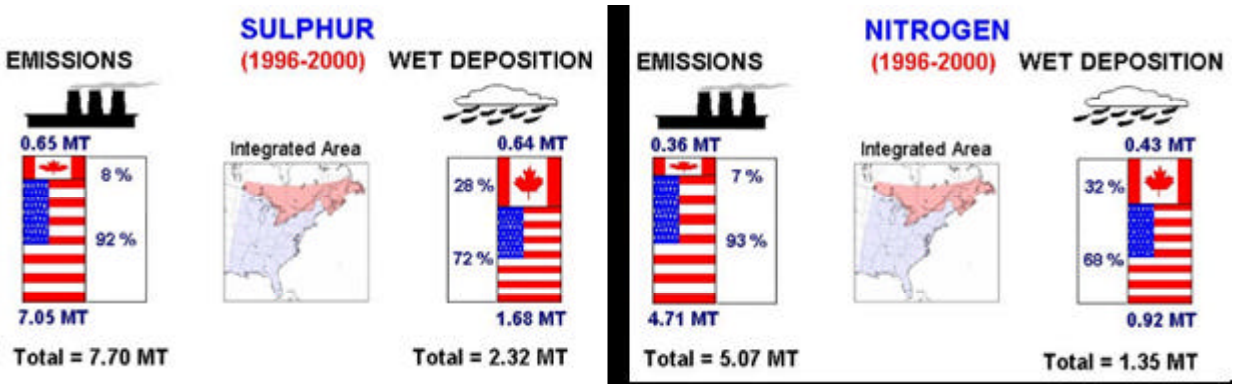


Figure 2.28: Five-year average (1996-2000) total emissions (megatonnes; MT) and wet deposition (MT) of sulphur and nitrogen over eastern Canada and the eastern U.S. (areas shown in map inset). The percentage values indicate the fraction of total eastern North American emissions and wet deposition in each country. (source: 2004 Canadian Acid Deposition Science Assessment. Environment Canada, released February 2005; full report available upon request)

Deposition data, collected by the CAPMoN network, combined with air mass trajectories, have been used to estimate the contribution of different emission source areas to total sulphur and nitrogen deposition in Ontario within 200 km of the U.S. border, Longwoods in the southwest and the Experimental Lakes Area in the northwest, are estimated to receive as much as 77 per cent of their total sulphur and nitrogen deposition from emissions in the U.S. The greatest impacts at these sites appear to be from U.S. emission sources in the Great Lakes, Ohio River Valley and the U.S. Midwest states.

2.7 Mercury

Mercury (Hg) is unique, as it is the only metal that is liquid at room temperature. It exists in the atmosphere primarily in the gas phase, as atomic (elemental) Hg^0 vapour. In this unreacted form, it is quite volatile, is relatively insoluble in water and generally resistant to reactions with other air contaminants. It is well established that elemental mercury is highly mobile in the environment due to its relatively high vapour pressure and long global atmospheric lifetime (estimated from several months to 1 year). When emitted as a gas, it can be dispersed globally such that mercury emitted in Russia and China may be deposited in Ontario, and vice-versa. Mercury can also be emitted as (or chemically transformed to) mercury chloride or oxide (Hg^{2+}) which can be deposited over short distances by precipitation scavenging or dry deposition. When mercury reaches a water body it can be converted to methylmercury which is toxic.

Mercury is of concern as an environmental contaminant because of its ability to accumulate in living organisms as methylmercury, potentially reaching concentrations that could pose a health hazard to humans and wildlife. Hence, the greatest risk to humans from mercury emitted to the atmosphere is in some of the foods we consume.

An example of the bioaccumulation of mercury occurs when mercury is deposited on lakes. Mercury can be taken up first by the lowest forms of life, algae, which in turn are consumed by smaller fish, and they by larger fish, which are often consumed by people who prefer fish caught in the wild. Potential health effects from exposure to mercury include reproductive and neurological/developmental effects such as impaired development in newborn and young children and it is a possible human carcinogen.

Mercury is emitted to the atmosphere from three sources: human activities (anthropogenic), natural (emissions from natural deposits) and re-emission from the Earth's surface of previously deposited Hg. The major sources of mercury to the atmosphere from human activities include fossil fuel (such as coal and oil) combustion, waste incineration, chlor-alkali plants and metal smelting and processing.

The anthropogenic use and release of mercury to the Ontario environment has fallen steadily over the past 30 years. At its peak over 60 tonnes per year of mercury was used in Ontario and most was released to the environment. In 2001, atmospheric releases from human activity in the province were estimated at 1.9 tonnes[17]. Electricity generation was the largest contributor, accounting for 31 per cent of overall emissions. Incineration was responsible for 20 per cent while Iron and Steel manufacturing accounted for another 12 per cent.

As of 2000, Ontario had reduced its atmospheric mercury emissions by 78 per cent of 1988 levels. Under the Canada-wide Standards process, Ontario has already set mercury release limits for incinerators and is currently developing mercury standards for coal-fired power generation.

Mercury emissions in the U.S. have decreased by about 50 per cent from 1990 levels to 104 tonnes[18] in 1999. Figure 2.29 below shows mercury emissions for the northeastern U.S. states and Ontario. Globally emissions of mercury from human activities were estimated to be about 1900 tonnes[19] in 1995 with mercury emission rates increasing over time.

[17] Great Lakes Commission Air Toxic Emissions Inventory, www.glc.org
[18] U.S.EPA AirData, oaspub.epa.gov/airsdata
[19] Mapping 1995 global anthropogenic emissions of mercury, Pacyna et. al.

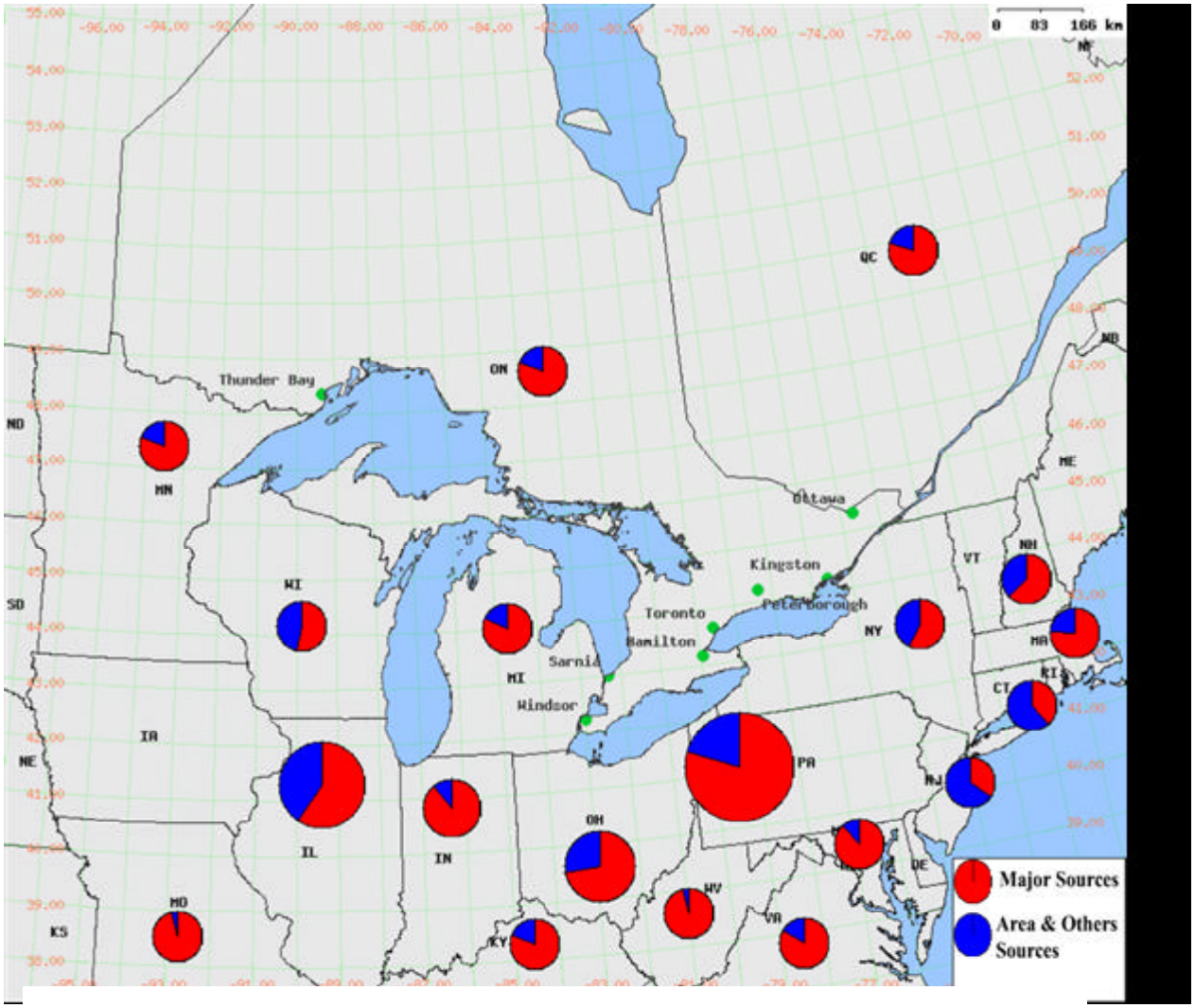


Figure 2.29: Mercury Emissions for Northeastern U.S. States and Ontario (1999)
Pie diameter is proportional to emission scale.
(source: Ontario Ministry of the Environment)

Since mercury is a global pollutant with global effects, it is widely found in the Ontario environment. Information on mercury levels in air over Ontario has only recently been available. The Ontario Ministry of the Environment has measured elemental mercury in air at several sites in Ontario. Annual average concentrations at Dorset in south-central Ontario were 1.6 ng/m^3 (nanograms per cubic metre) while two sites in the GTA had annual concentrations in the 1.9 to 2.4 ng/m^3 range. These are typical of values at rural and urban sites in North America.

Environment Canada operates the Canadian Atmospheric Measurement Network (CAMNet), a network of eleven permanent stations across Canada, three of which are in Ontario. The CAMNet data reveal that average elemental mercury concentrations vary between sites across the country, from 1.33 ng/m^3 at Kejimkujik National Park, Nova Scotia to 1.9 ng/m^3 at Point Petre, Ontario. The average concentrations at the other two Ontario sites, Egbert and Burnt Island were 1.65 and 1.58 ng/m^3 respectively.

Annual average concentrations of mercury in precipitation at Egbert in south central Ontario ranged from 7 to 10 ng/L (nanograms per litre) for the 2001 to 2003 period[20]. It is important to note that total mercury concentrations in precipitation are 3 to 5 times higher than in streams and lakes. This implies that precipitation is a net source of mercury to watersheds and lakes. The global background mercury concentration in precipitation is believed to be less than 5 ng/L (remote sites such as in Newfoundland measure less than 5 ng/L).

In Ontario, data is available on mercury concentrations in various fish species taken from over 1700 water bodies. Lakes with fish containing elevated levels of mercury can be found across the province, and are not confined to areas associated with point sources of mercury release. Mercury concentrations in fish have declined in areas where point source releases of mercury have been reduced, however in lakes remote from point sources, the concentration of mercury in fish has not exhibited any measurable trend.

Ontario has recognized the risk to consumers of (sport) fish caught in the wild and since 1977 has published the *Guide to Eating Ontario Sports Fish*. The 2005-06 edition of the guide, now available on-line at www.ene.gov.on.ca/envision/guide/index.htm advises anglers on the number of meals that can be consumed each month of specific sizes of fish from the respective locations.

Although mercury is a global problem, the precipitation concentrations in Ontario and at most sites in the U.S. and Canada are higher than global background values. As previously noted, mercury emissions were estimated to be 104 tonnes in the U.S. in 1999 and 1.9 tonnes in Ontario in 2001. This indicates that regional and local mercury emissions from the U.S. and Canada are contributing to mercury deposition in Ontario. Overall the impact of mercury emissions from U.S. sources on Ontario is believed to be far greater than the converse, given the significantly larger emissions in the U.S.

[20] National Acid Deposition Program/Mercury Deposition Network, nadp.uiuc.edu/nadapdata

As an emerging regional air issue for Ontario, and as a pollutant that can persist long enough in the atmosphere to be transported over large distances, linkages between significant sources of mercury and transboundary receptor areas need to be examined. For this, mercury emission inventories need to be improved and attempts to model the transport and deposition of this contaminant need to be expanded.

3.0 Modelling Air Pollution in Ontario

Models serve various predictive purposes when applied to the movement of air pollution. In the most general terms they use complex mathematics and powerful computers to simulate reality. If the amounts of pollution released into a regional airshed from known sources, and the weather data for that region are provided to it, an air quality model can calculate the concentrations of selected pollutants throughout that region, for the time period the weather and emission data represent. By examining emissions released in portions of the region, air quality models can determine the origins of polluting "air parcels" impacting on particular geographical locations within the region. Models are the only tools currently available which allow investigation of "what if" scenarios, most particularly "what if emissions in a certain region are reduced?"

The Ontario Ministry of the Environment has a long history of developing and applying regional atmospheric models, either alone or in cooperation with others. For example, the MOE was extensively involved in the development and application of the Acid Deposition and Oxidant Model (ADOM). This model was first applied in the late 1980s for acid deposition assessments and was used for the modelling of the 2004 Canadian Acid Deposition Science Assessment Report.

As part of the Canada-wide Standard agreement of 2000, the Ontario and the Canadian federal governments agreed to examine together the issue of transboundary movement of ozone, fine particulate matter and their precursors through new regional modelling studies. The studies will assist the governments in determining for reporting purposes, the conditions under which Ontario and the federal government would meet their respective obligations under the CWSs[21]. For these studies, emissions of smog precursors from a region that included Ontario, Quebec and that part of the United States east of the Mississippi and south to include Tennessee and North Carolina were used with meteorology (weather) data sets for specific time periods, to project ambient pollutant levels for those same times across the entire region.

An air quality model provides estimates of ozone and fine particulate matter across the region. To predict concentrations of ozone, the model includes the impacts of background ozone that originated outside the modelled emission region described above. Emissions of the precursor gases NO_x, and VOCs from within the region react in the presence of sunlight to form additional ozone which is added to the background ozone. Both background ozone and ozone resulting from precursor emissions in the model region contribute on days when ambient levels are above 65 ppb for an 8-hour running average.

Ozone concentrations are often higher in suburban and rural areas than in large urban centres. Emissions of nitric oxide (NO) in large urban areas can scavenge (i.e. react with) some of the ozone transported into the area which reduces ozone concentrations and

[21] Guidance Document on Achievement Determination, Canada-wide Standards for Particulate Matter and Ozone, Canadian Council of Ministers of the Environment, Winnipeg, Manitoba, 2002, www.ccme.ca

increases nitrogen dioxide (NO_2). Further downwind, NO_2 along with sunlight react to produce ozone. Air quality models simulate these processes to predict where ozone concentrations would be highest and what emission sources contribute to the high concentrations.

Fine particulate matter ($PM_{2.5}$) originates from particles emitted directly from sources (primary $PM_{2.5}$) and from particles formed in the atmosphere (secondary $PM_{2.5}$). The precursor gases SO_2, NO_x, ammonia and certain VOCs react in the atmosphere to form ammonium sulphates, ammonium nitrate and organic particles. Air quality models include all of these components that are part of $PM_{2.5}$. High concentrations of $PM_{2.5}$ can result from a combination of local emissions of primary particulates and region wide emissions of precursor gases such as SO_2.

In 2004 Ontario Ministry of the Environment scientists used the Community Multi-scale Air Quality model[22] (CMAQ), developed by the US Environmental Protection Agency to track multiple pollutants simultaneously across a region, to model the 1998 smog season. There were a relatively high number of days in the spring and summer of that year, during which ozone levels exceeded Ontario's one-hour criterion of 80 ppb, providing a representative selection of all levels of air quality. Recent advances in computer speed and onboard storage and retrieval capacities allowed the study to embrace a much longer period of time (May through September) than earlier modelling studies for Ontario. Performing model runs for a five month period provides information on how variations in meteorology affect episode days and provides better insight into what sources contribute on "cleaner" days.

The results of the CMAQ simulations, inputting emissions data such as shown in Figures 3.1 and 3.2, were used to assess the influence of transboundary flows of ozone, fine particulate matter and their precursors on the 16 sub-regions shown in Figure 3.3. These modelling sub-regions include all Ontario communities with a population of approximately 100,000 or more that are required to report ozone and $PM_{2.5}$ concentrations, consistent with the intent of the CWS Guidance Document on Achievement Determination. Sub-domains outside Ontario were chosen to reflect those areas most likely to be impacted by Ontario emissions.

[22] The Community Multi-scale Air Quality (CMAQ) model was developed, and released for general use in 1998 by the United States Environmental Protection Agency www.epa.gov

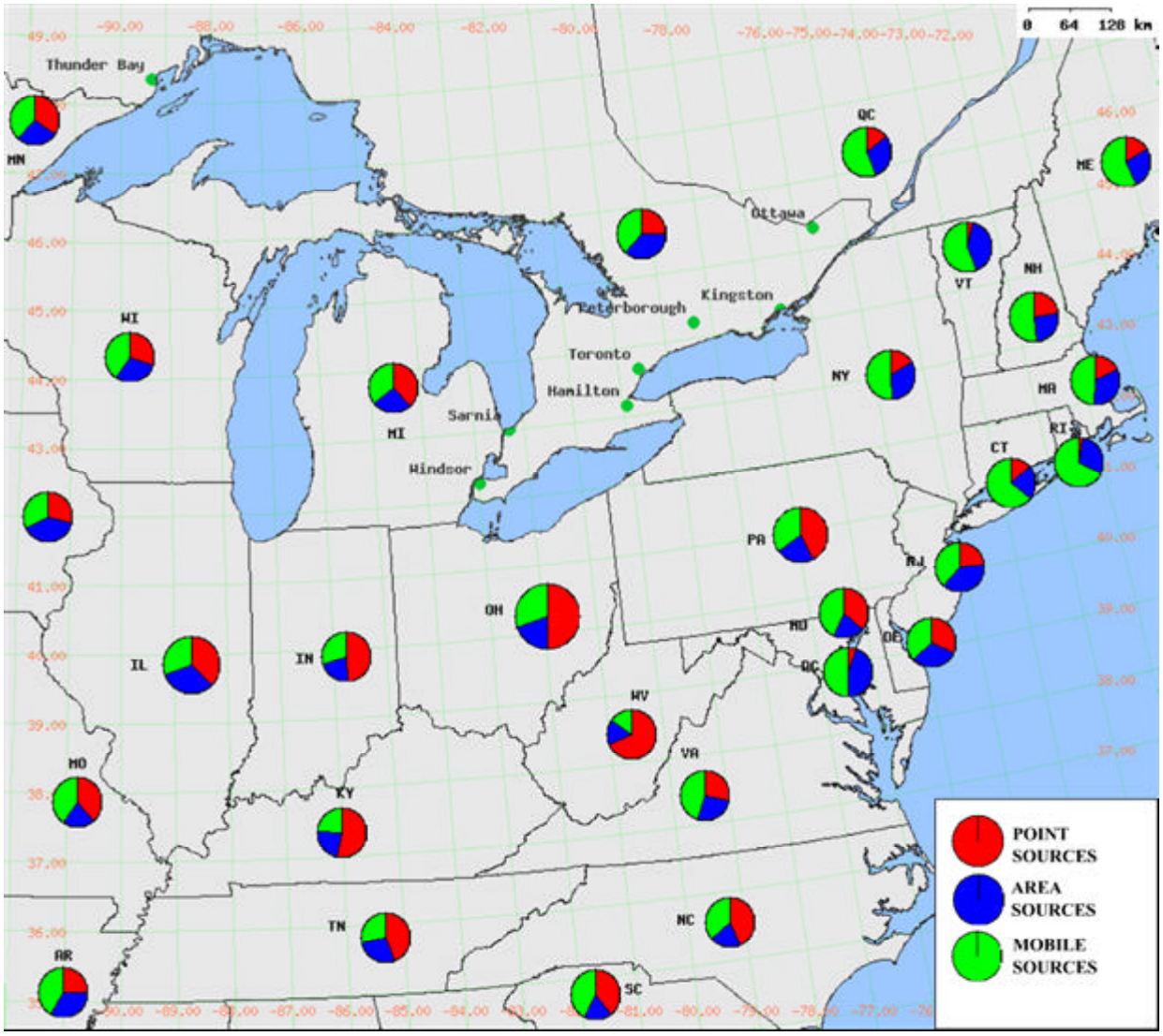


Figure 3.1: Emissions of NO_x for each state/province, superimposed as pie charts of varying size representing total emissions and the sector contributions.
1995 Canada and 1996 U.S. emission inventories.
(source: Ontario Ministry of the Environment)

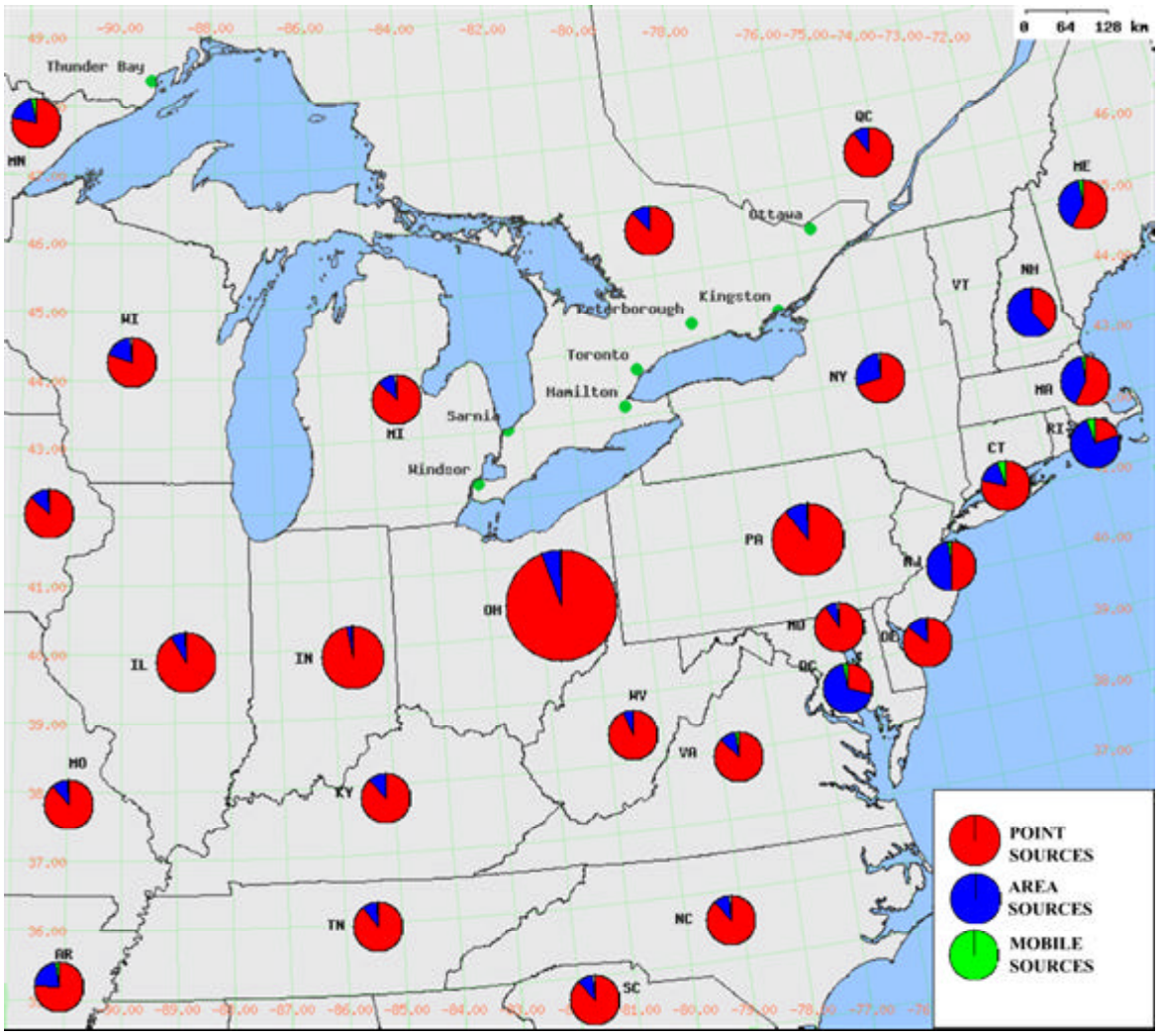


Figure 3.2: Emissions of SO_2 for each state/province, superimposed as pie charts of varying size representing total emissions and the sector contributions.
1995 Canada and 1996 U.S. emission inventories.
(source: Ontario Ministry of the Environment)

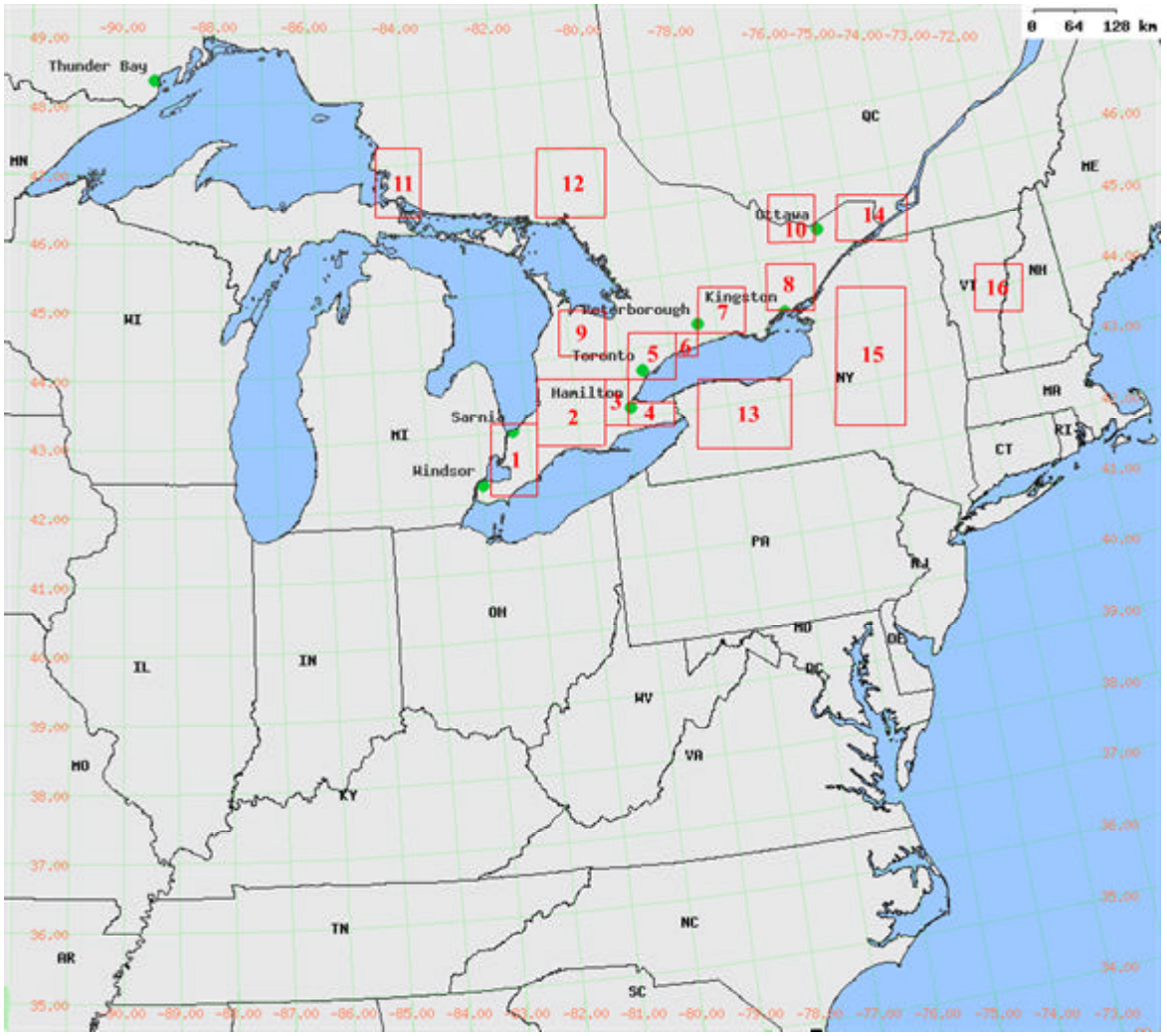


Figure 3.3: Sub-regions over which model predicted ambient ozone and $PM_{2.5}$ concentrations were assessed.

(source: Ontario Ministry of the Environment)

The models were first run using emissions from all parts of the region. As a check on the accuracy of the models, the predicted concentrations were compared with actual air quality measurements over the 5 month time period. The models were then rerun but with Ontario emissions from human activity set to zero. The main study results are shown in the following three figures. The green wedge in each pie represents the Ontario contribution. The blue wedge is the sum of transboundary and global background pollutant levels.

From Figure 3.4 it can be seen that setting Ontario emissions to zero on high ozone concentration days (days when 8-hour running average ozone concentrations were above the Canada-wide level of 65 ppb) would have reduced ambient ozone concentrations by 1

per cent in Windsor, 9 per cent in the GTA, 16 per cent in Oshawa and 7 per cent in Kingston. That is, on those days during the summer of 1998, when modelled ozone levels in the province were above the CWS, Ontario emissions contributed to at most 16 per cent of the problem, and much less than that across much of the province. The largest contribution due to Ontario's emissions was downwind of the Greater Toronto/Hamilton areas.

Very large day-to-day variability was found in the reductions for each of the sub-domains, due to changing meteorology. For Windsor through to the GTA, there were some days when modelled disbenefits were found; that is, by reducing the Ontario emissions to zero, the ozone concentrations actually increased. Removing ozone scavenging by nitric oxide in urban areas is believed to be the cause of the disbenefits.

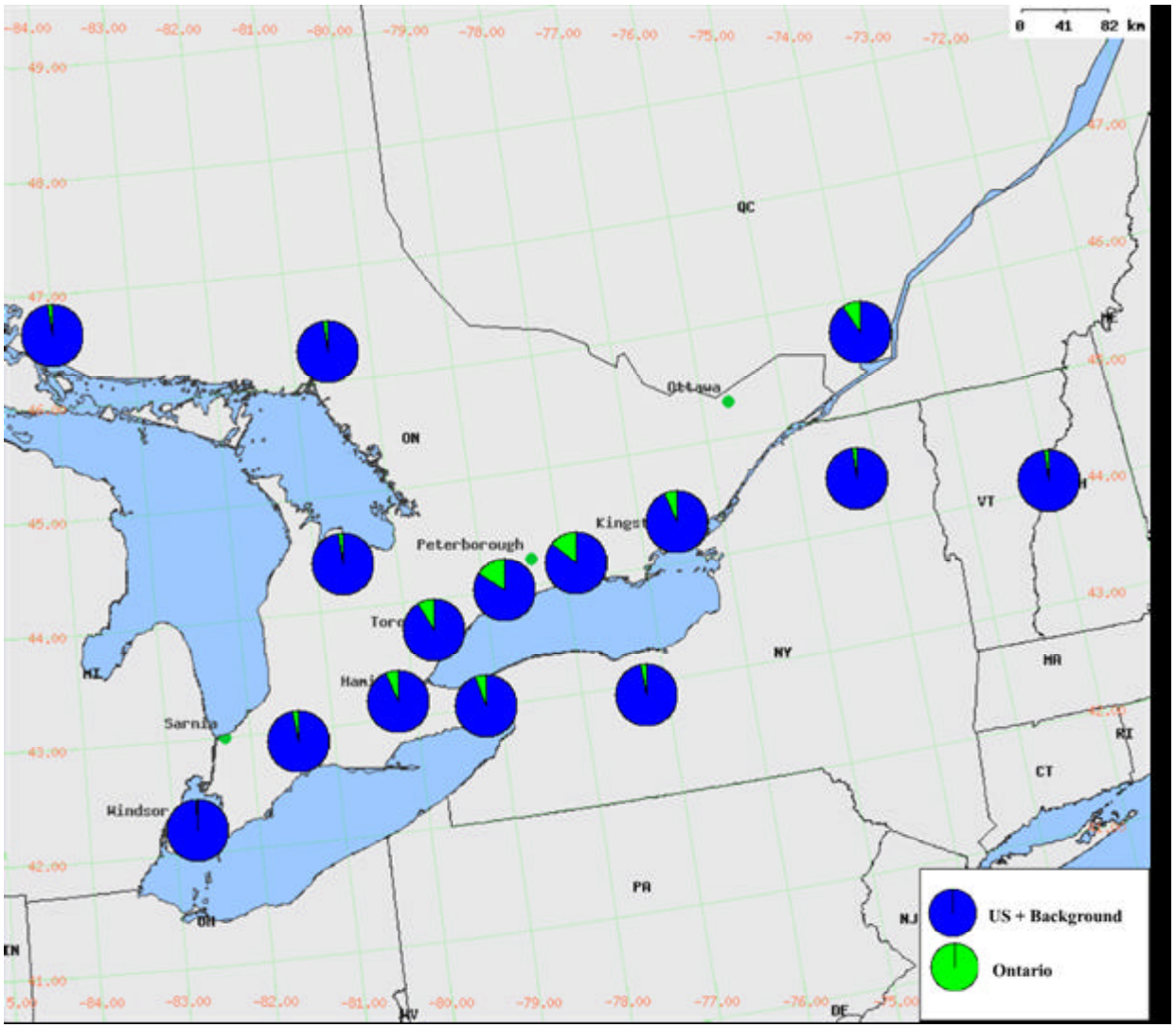


Figure 3.4: Graphic of Transboundary vs. Ontario Contribution for Ozone on High Concentration Days during 1998 Spring/Summer Season.
(source: Ontario Ministry of the Environment)

The large contribution from U.S. emissions and background ozone presents a significant challenge. Efforts to reduce ozone on high concentration days by Ontario alone would have only small benefits for Windsor through to the GTA with larger benefits downwind of the GTA. Reductions in precursor emissions in the U.S. would be needed to significantly affect ozone in southwestern Ontario on these days.

For particulate matter, the picture is a little more encouraging. In Figure 3.5, a similar graphic display is provided for $PM_{2.5}$ on days when the daily average $PM_{2.5}$ levels exceed the CWS reference level of 30 $\mu g/m^3$. The Ontario contribution is highest in the Greater Toronto Area (GTA) at approximately 49 per cent, and declining in all directions from there.

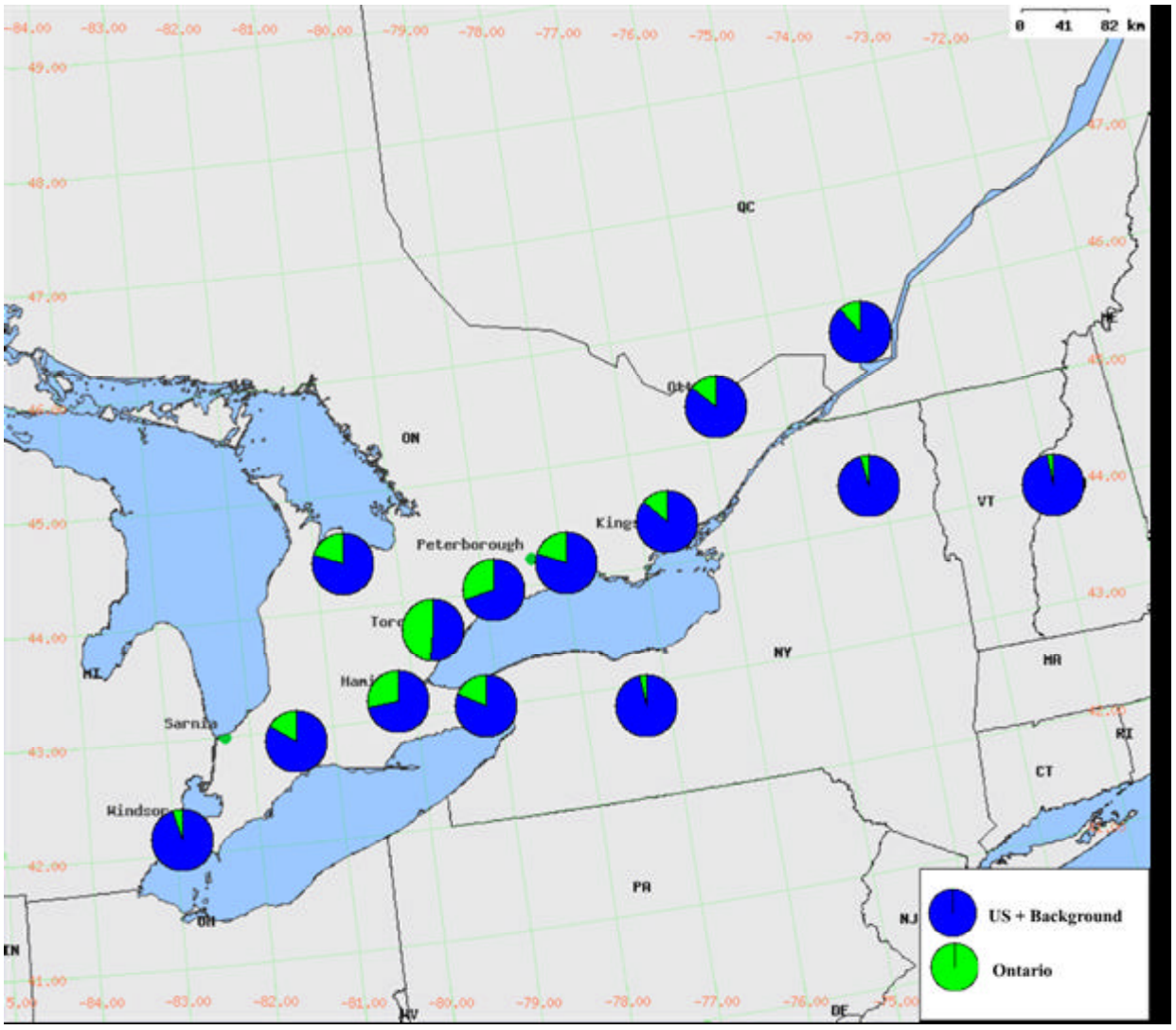


Figure 3.5: Graphic of Transboundary vs. Ontario Contribution for $PM_{2.5}$ on High Concentration Days during 1998 Spring/Summer Season.

(source: Ontario Ministry of the Environment)

In the GTA, during a smog episode, approximately half of the $PM_{2.5}$ arises from emissions from human activity in Ontario. In Windsor the picture is similar to ozone: no amount of effort, by those living in the area, will improve air quality in a significant way during smog episodes. In the area from Hamilton to east of Toronto, the impact of Ontario's emissions of $PM_{2.5}$ precursors and primary $PM_{2.5}$ is significant, however further downwind in Kingston, the sum of transboundary and regional background concentrations again dominant the impacts.

As illustrated in Figure 3.6, when the results of the air quality modelling of $PM_{2.5}$ are averaged over all days throughout the five-month period, Ontario emissions are seen to have a greater impact than on dirty days as depicted in Figure 3.5. Still however, only in the GTA does the Ontario contribution exceed 50 per cent. Other communities from Windsor to Ottawa, had reductions in $PM_{2.5}$ concentrations by 20 to 40 per cent when Ontario's emissions due to human activity were set to zero.

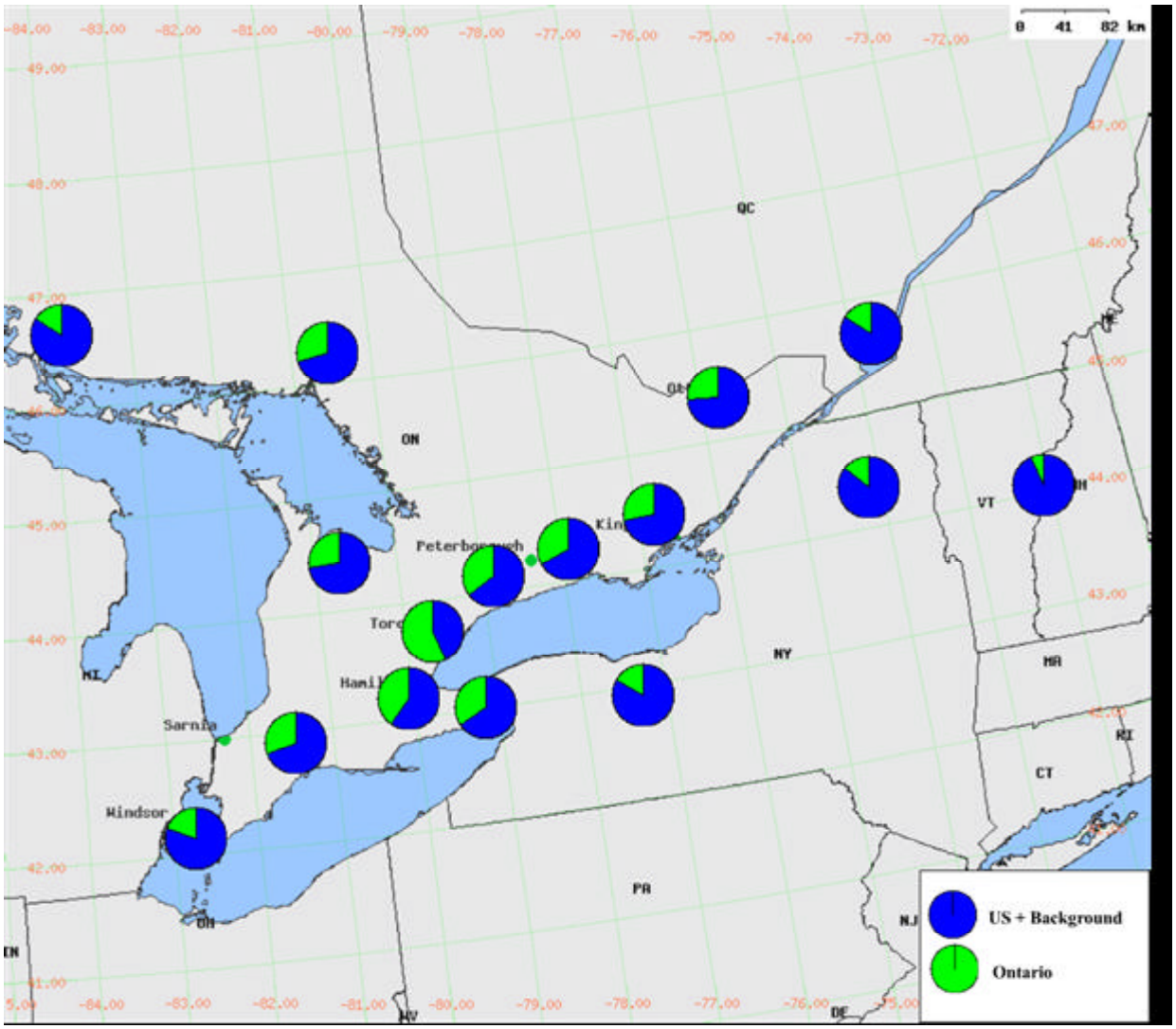


Figure 3.6: Graphic of Average Transboundary vs. Ontario Contribution for $PM_{2.5}$ during 1998 Spring/Summer Season.
(source: Ontario Ministry of the Environment)

3.1 Impact of Ontario's Emissions on Downwind Jurisdictions

Ontario recognizes that it is not only the recipient of transboundary air pollution, but the province contributes to the problem in downwind jurisdictions such as Quebec, the U.S. New England states and the Canadian Maritime Provinces. In recent years New York has been particularly critical of emissions from Ontario, and most specifically emissions from Ontario Power Generation's Nanticoke Generating Station on Lake Erie. The question is "to what degree do Ontario emissions impact downwind jurisdictions?"

To address those concerns and in particular those of New York, modelling runs done as part of the recent study were assessed for sub-regions representative of U.S. jurisdictions. Sub-regions 13 and 15 in particular cover upper state New York with sub-region 16, located in Vermont and New Hampshire. Ontario's impacts on high ozone days in the Upper New York state and Vermont/New Hampshire region were small at approximately three per cent.

Ontario emissions contribute up to approximately 20 per cent of the $PM_{2.5}$ loadings in the upper state New York area on average days and about 7 per cent in Vermont and New Hampshire. On days when ozone and $PM_{2.5}$ concentrations were high, the modelled results showed that Ontario generally contributes about 5 per cent to New York and about 3 per cent in Vermont and New Hampshire. The impact of New York emissions on Ontario was not modelled, but would not be zero.

Neighbouring areas in Quebec are also impacted by Ontario's emissions. Modelling results show that Ontario emissions contribute approximately 16 per cent of $PM_{2.5}$ loadings on average days and at most, 12 per cent on days when ozone and $PM_{2.5}$ concentrations were high.

3.2 Other Older but Relevant Studies

Prior to the 2004 results reported here, other studies using the CMAQ computer model were conducted including one in 2002 carried out in cooperation with Environment Canada[23]. The results of that study generally confirm those found in the more recent study. Due to computing limitations at the time, the 2002 work covered much shorter (two 9-day) time periods. The study did however include a winter period, when the composition of $PM_{2.5}$ is different. In summer $PM_{2.5}$ is formed more from sulphates, in winter more from nitrates.

From these results the study authors drew several broad conclusions, reproduced here:

- It is clear that significant reductions in PM concentration(s) can only be achieved by reducing primary precursor emissions across the entire domain. Reductions in

[23] *Summary Report – Implementation of the Models-3/CMAQ Modelling System for PM and Ozone,* MOE/EC Model Development and Assessment Working Group, August, 2002

Canadian emissions alone are relatively ineffective in reducing ozone and particulate matter concentrations in the province, especially in the summer time.

- For the wintertime episode, reductions in Canadian emissions, while still producing a smaller effect than domain-wide reductions, were somewhat more effective than was the case in the summer. This is consistent with the fact that the atmosphere was much more stagnant for the winter episode, meaning that emissions were not transported the distances they were in summer and consequently had a greater impact in their local area.

3.3 Strengths and Weaknesses of Air Quality Modelling

Air quality modelling studies such as these have both strengths and limitations. In both studies presented here, emission inventories from the late-1990's rather than more recent data were modelled due to the lack of more recent, complete emission inventories from the various jurisdictions. Emissions inventories for fossil-fueled power plants, for example, are available for recent years but emissions from area sources have not been updated as frequently.

Although extremely useful at guiding public policy, modelling has associated uncertainties (as does the analysis of measurement). Numerous assumptions must be made in constructing a model and each piece of data entered into the model has itself, a degree of uncertainty around it. For example, the model results are sensitive to the quality of the meteorological data used in the assessments. Variations from day to day in emissions from large sources such as power plants could also affect predicted results for a particular episode.

Modellers will, as part of each study, compare the outputs from the studies to real air quality data from the time period studied. In the studies described above, scientists compared modelled and measured concentrations of ozone and particulate matter. In the 2004 study, they concluded that: "(A)although there were some discrepancies between modelled and observed data for individual days and episodes, the differences appear to be random due to small shifts in meteorological fields". They further concluded that the model "performed well". As the science of air quality modelling is refined and advanced, it will continue to improve in its ability to mathematically replicate reality.

Notwithstanding modelling uncertainties these studies and the air quality data presented in Chapter 2 are in general agreement and supportive of each other. Ontarians will only enjoy substantially cleaner air, particularly on those days when air quality standards are exceeded, when major emission reductions are made in upwind US states. This same conclusion was reached by the State of New Hampshire in their report Air Pollution Transport and How it Affects New Hampshire.[24]

[24] Air Pollution Transport and How it Affects New Hampshire, New Hampshire Department of Environmental Services, May 2004

4.0 Human and Economic Implications of Ozone and Airborne Particulate Matter Due to Emissions by Ontario and the United States

4.1 Background

The following is a summary of a report, to be published by DSS Management Consultants Inc. (DSS), of the physical and economic damages in Ontario attributable to provincial air pollutant emissions and transboundary air pollution. The purpose of the study is to estimate health and environmental damages associated with air pollution. These damage estimates are expressed in both physical and economic terms and provide insight into the nature, magnitude and distribution (both spatially within Ontario and among sensitive receptors) of these damages.

All damages are expressed as annual values and are estimated for 2003 only. As air quality, the demographics of the province and the inventory of sensitive environmental receptors change over time, these damages will likewise change. Health damages in particular, are expected to increase substantially in the future even if air pollution remains constant. This trend is due to an expanding and aging population. The cumulative total damages from air pollution, that can be expected over the next 20 years, will be substantial.

The focus of this study is on health and environmental risks associated with the key ingredients of smog, ground-level ozone and particulate matter (primarily fine particulate matter less than 2.5 microns in aerodynamic diameter denoted as $PM_{2.5}$).

Air pollution risks were estimated across all of southern and central Ontario[25]. Census divisions (CD) were used as the finest level of spatial resolution. In total, 44 CDs were included. The blue circles on Figure 4.1 represent the population-weighted centroids for each CD. These CDs are grouped to produce regional damage estimates.

The overall results of this study are presented first followed by further details concerning the methodology and information sources which were used to derive these damage estimates. Where possible and helpful, damages were reported in both physical and economic units of measure.

[25] The five northernmost census divisions (CDs), namely, Rainey River, Kenora, Thunder Bay, Cochrane and Timiskaming, are not included. Air quality forecasts were not available for these areas.

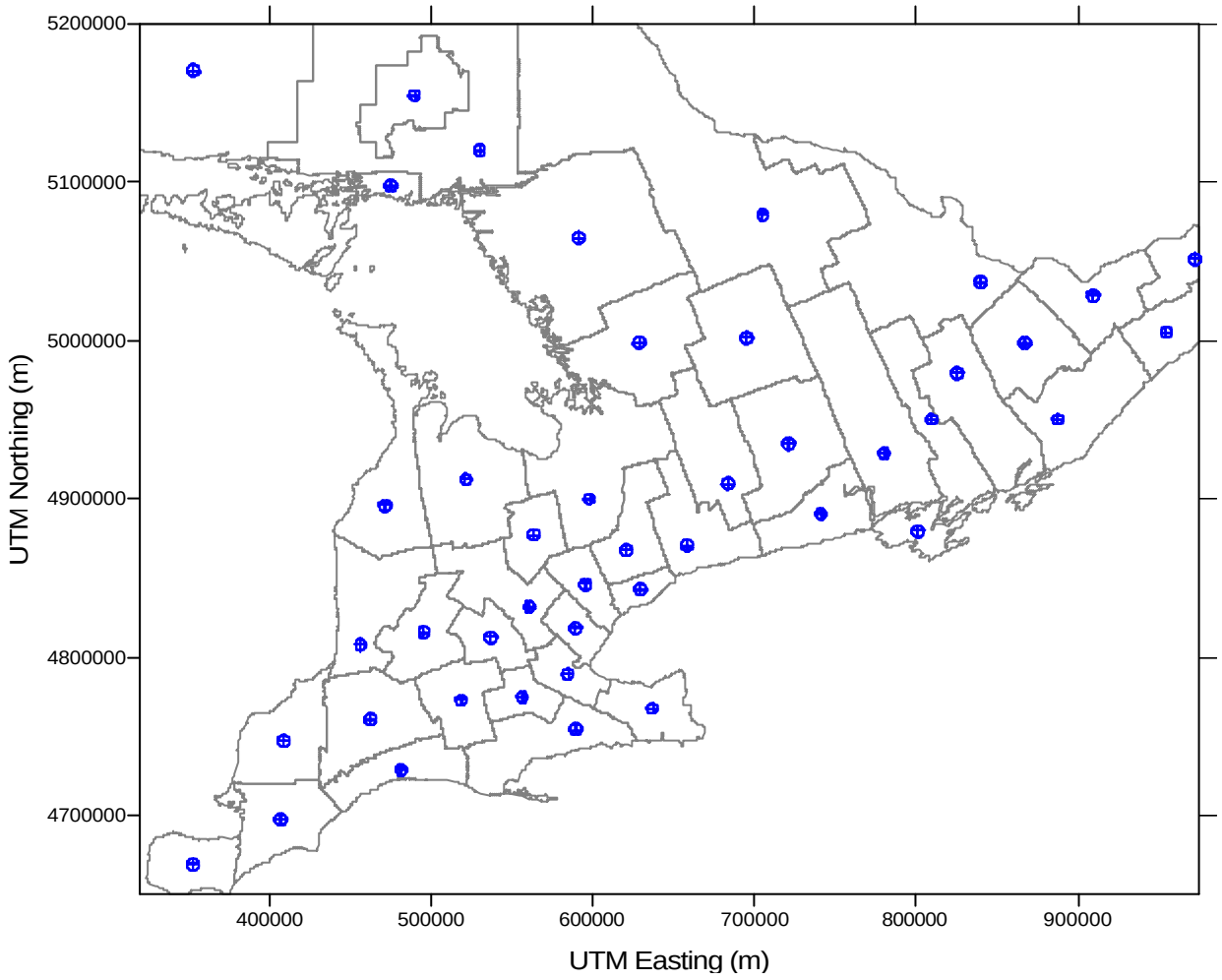


Figure 4.1: Map Showing Location of Census Division Centroids
(source: DSS Management Consultants Inc.)

4.2 Results Highlights

4.2.1 Total Damages

Table 4.1 presents the total estimated annual economic damages of air pollution in Ontario. Ontario is incurring almost $10 billion in health and environmental damages each year. Of this total, approximately 55 per cent is attributable to transboundary air pollution, defined as air pollution resulting from U.S emissions being transported into Ontario for purposes of this section of the report. The remainder is attributable to Ontario emissions of air pollutants.

Health damages comprise about 70 per cent of the total economic damages or about $6.6 billion per year. Of this total, the economic value associated with increased risk of premature mortality plays a major role.

The remaining 30 per cent comprises environmental damages. Most of these environmental damages are attributable to losses associated with reduced visibility, damages to buildings and structures and soiling of household materials.

Table 4.1: Summary of Health and Environmental Damages

	Damages ($Billions/a)		
	Ontario	**Transboundary**	**Total**
Health	**2.9**	**3.7**	**6.6**
Environment	**1.5**	**1.5**	**3.0**
Total	**4.4**	**5.2**	**9.6**

The distribution of these damages and the proportions attributable to the two sources vary considerably among the various regions of the province (Figure 4.2 and Table 4.2). As expected, southwestern Ontario experiences a large proportion of damages attributable to transboundary air pollution. It is important to note that these days relate to all days, both "clean" and "dirty", since ozone and $PM_{2.5}$ have very low or no health thresholds.

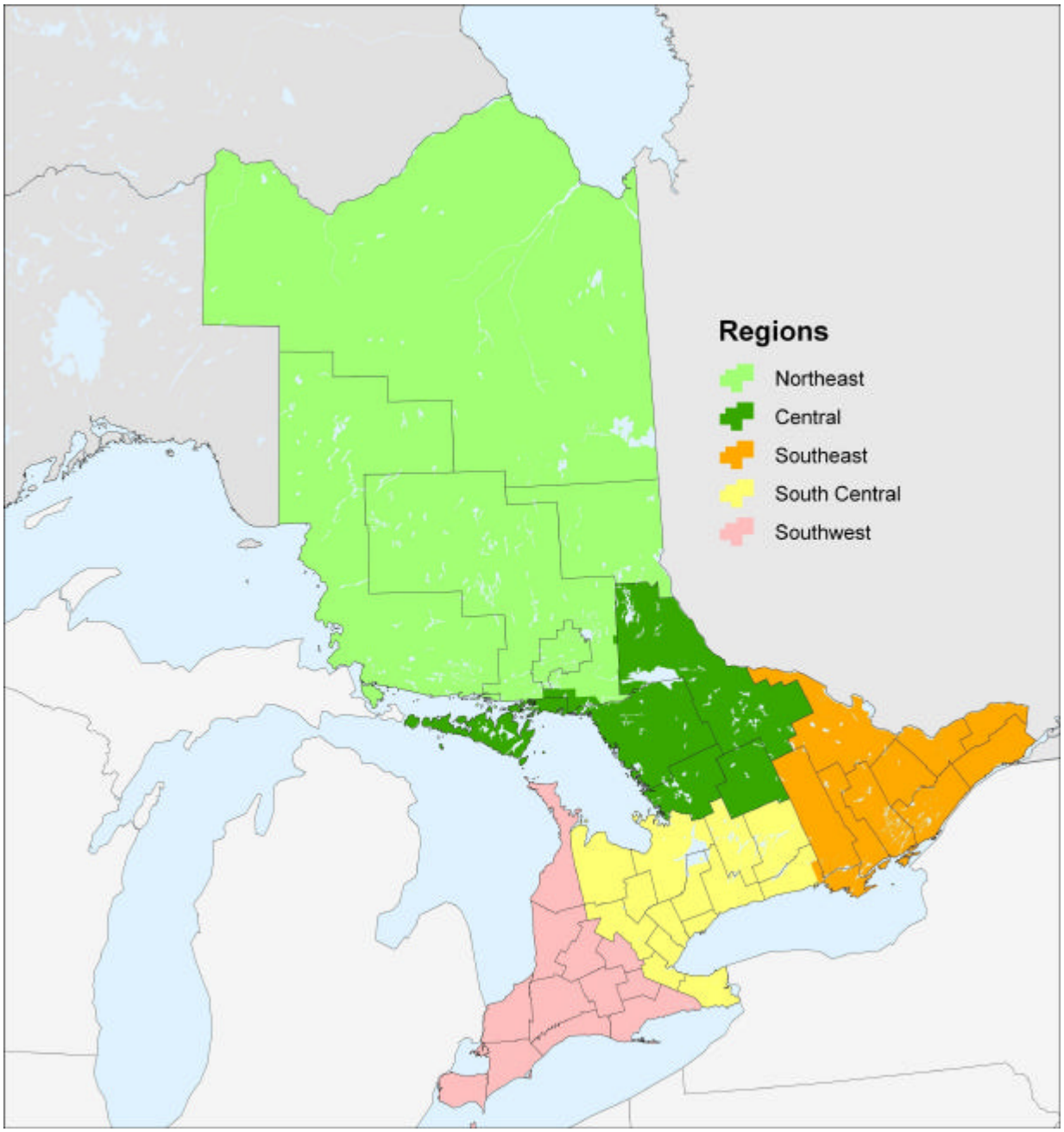


Figure 4.2: Regions of Ontario Used in Study.
(source: Ontario Ministry of the Environment 2005)

Table 4.2: Summary of Damages by Ontario Regions

	Damages ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**103**	**163**	**266**
Central Ontario	**74**	**138**	**212**
Southeast Ontario	**429**	**689**	**1,118**
South Central Ontario	**3,212**	**2,647**	**5,859**
Southwest Ontario	**501**	**1,629**	**2,130**
Total	**4,319**	**5,266**	**9,585**

Following is a more in depth summary of the damage estimates for individual damage categories.

4.2.2 Air Pollution Modelling

As described in Section 3 the Ministry of the Environment used a sophisticated air quality model to predict regional air pollution dynamics. This model was used to generate forecasts of the average contributions of air pollution that are attributable to background sources, provincial emissions and transboundary transport of air pollution. These forecasts are based on 1998 data for the months of May to September inclusive. The proportions were estimated for $PM_{2.5}$ and 8-hour and 1-hour ozone concentrations. Meteorological data from 1998 were used since they are reasonably representative of weather systems typical for that period of the year[26].

Average ambient concentrations for each of the pollutants were derived for each census division as part of an updating of the Illness Costs of Air Pollution (ICAP) model (DSS,

[26] Personal communication, Dr. Robert Bloxam, MOE

2005). These ambient concentrations were geographically interpolated from Canadian and U.S. air quality monitoring data.

By combining the forecast relative proportions estimated by the Ministry of the Environment with the absolute concentrations derived from the interpolated monitoring data, estimates of the absolute contribution of each source to the ambient concentration were derived for each CD.

4.2.3 Health Damages

The basic methodology used in this study is the latest version that was used by the Ontario Medical Association (OMA) to estimate health damages in Ontario from air pollution (DSS, 2001; DSS, 2005). ICAP includes five major health risk categories (i.e., premature death, hospital admissions, emergency room visits, doctor's office visits and minor illnesses). Each of these major categories are further divided into more specific health outcomes. In total, ICAP includes 23 specific categories of health effects associated with air pollution. For each of these health outcomes and each pollutant type and each age group in the exposed population, the individual risk of exposure is estimated[27].

The health damages forecast by ICAP are converted to economic values by estimating the economic costs associated with each type of health outcome. These economic costs included the value of avoiding premature death, pain and suffering, cost of treatment and lost productivity/time.

ICAP estimates the number of premature deaths attributable to exposure to air pollution. Expressing the results in terms of expected numbers of premature deaths (or another specific health outcome) is a simple way to communicate the change in risk of premature mortality that occurs when members of a population are exposed to a change in air quality. More accurately, what is being forecast is the average change in risk that each individual in the exposed population experiences with a change in air quality.

Economists commonly use a measure referred to as the *value of a statistical life* (VSL) to value changes in the risk of premature mortality. The VSL is a measure of people's willingness to pay to reduce their risk of premature mortality. Combining these individual sums produces an estimate of the value to society if reducing health risks associated with air pollution.

[27] Note: ICAP does not contain any relative risks for doctor's office visits. The epidemiological literature contains few estimates of these risks due to data limitations. As a result, the health damages reported in this study do not include estimates of damages associated with increases in doctor's office visits.

Health Damages – Physical Damages

Table 4.3 provides a breakdown of health cases attributable to air pollution in Ontario. Almost 5,000 premature deaths annually were associated with air pollution, more specifically, $PM_{2.5}$. In addition, more than 18,000 hospital admissions and approximately 22,000 emergency room visits were associated with air pollution. Minor illness cases approached 5 million. These results are generally consistent with the proportions expected; the frequency of cases tends to decline with the severity of the illness.

More than half of all the cases are attributable to transboundary air pollution. These results clearly indicate that transboundary air pollution is causing Ontario residents to get sick and in some cases, to die prematurely.

Table 4.3: Health Cases Attributable to Ontario and Transboundary Air Pollution

	Attributable Health Cases			
	Ontario	**Transboundary**	**Total**	**Ontario Proportion**
Premature Death	**2,130**	**2,751**	**4,881**	**44%**
Hospital Admissions	**6,541**	**11,939**	**18,480**	**35%**
Emergency Room Visits	**7,950**	**13,925**	**21,875**	**36%**
Minor Illnesses	**2,119,608**	**2,682,437**	**4,802,045**	**44%**

Table 4.4 shows the breakdown of the economic damages associated with health impacts by region of the province. The great majority of the damages are concentrated in the south central region where the majority of the population resides. However, slightly more than 50 per cent of the damages in this region are attributable to Ontario air pollution emissions. The high rate of vehicle emissions likely accounts for this result. Nonetheless, even relatively remote regions of the province (e.g., northeastern Ontario) suffer significant economic damages due to air pollution. The majority of the damages in these rural parts of the province are attributable to transboundary air pollution.

Table 4.4: Regional Distribution of Economic Health Damages

	Health Damages ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**43**	**87**	**130**
Central Ontario	**34**	**84**	**118**
Southeast Ontario	**262**	**493**	**755**
South Central Ontario	**2,166**	**1,992**	**4,158**
Southwest Ontario	**361**	**1,067**	**1,428**
Ontario Total	**2,866**	**3,723**	**6,589**

The great majority of the economic losses associated with health damages are attributable to premature mortality. This result is common with health damage assessments which have been undertaken else where in Canada, the U.S. and Europe. The public places a high value on avoiding the risk of premature death.

4.2.4 Environmental Damages

Five types of environmental impacts associated with air pollution have been analysed, namely, loss of agricultural and forest productivity, damages to buildings and structures, visibility impairment, and soiling of materials. Quantitative damage estimates were produced with a large spreadsheet model, which combined inventories of sensitive receptors, air quality data, damage functions and monetary damage coefficients to arrive at estimates of physical and economic damages.

Table 4.5 provides a summary of the economic value of environmental damages by major category. The largest economic damages are associated with impaired visibility (i.e., $1.3 billion). Materials damages account for close to another $1 billion. Forestry and agriculture combined total about $280 million in damages.

Table 4.5: Summary of Economic Losses from Environmental Damages

	Attributable Monetary Damages ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Agriculture	**$36**	**$165**	**$201**
Forestry	**$26**	**$51**	**$77**
Materials	**$664**	**$310**	**$974**
Visibility	**$538**	**$779**	**$1,317**
Soiling	**$188**	**$238**	**$426**
Total	**$1,452**	**$1,543**	**$2,995**

4.2.4.1 Agriculture Damages

The magnitude of agricultural damages depends on many factors including crop types, soil conditions, and the timing, duration and intensity of exposure. This analysis deals only with the effects of direct impingement of ozone on foliage and resulting impacts on crop yields. The primary air pollutant affecting agricultural crops in terms of foliar damage is ozone. Damages associated with soil acidification are not included.

Yield information was obtained for each crop at the county level. Crop-specific concentration-response functions were derived from the scientific literature. These damage functions were used to calculate the yield of Ontario crops in the absence of any anthropogenic ozone (i.e., the "natural" yield). The impact of anthropogenic ozone was calculated by taking the difference between the natural yield and the current reported base yield (i.e., total anthropogenic yield loss). The Ontario and transboundary proportions were calculated based on their relative contribution to the total anthropogenic ozone concentration.

The economic value of these damages was estimated by multiplying the loss in yield by the average price. Local county prices for the 21 crop types were obtained for this purpose.

Agriculture Crops – Physical Damages

Table 4.6 presents the estimated crop losses. These results indicate that air pollution and in particular, ozone is currently having a major effect in Ontario in terms of reduced agricultural yields for a broad range of crop types. However, the overall effect is difficult to appreciate since the unit prices of these crops vary over a considerable range.

Table 4.6: Physical Damages by Crop Group

	Attributable Crop Losses (1,000 tonnes)		
	Ontario	**Transboundary**	**Total**
Grain Crops [a]	**115.7**	**496.4**	**612.1**
Bean Crops [b]	**39.1**	**203.2**	**242.3**
Market Vegetables [c]	**16.3**	**83.2**	**99.5**
Grapes	**0.4**	**1.9**	**2.3**
Hay	**64.1**	**190.0**	**254.1**
Tobacco	**0.1**	**0.2**	**0.3**
Total	**235.7**	**974.9**	**1210.6**

a: winter and spring wheat, oats, barley, mixed grains, canola, seed and fodder corn
b: soybean, white field beans
c: tomatoes, potatoes, onions, green peppers, sweet corn, green beans, cabbage, carrots

Agriculture Crops – Economic Damages

Table 4.7 expresses these crop losses in economic terms. The total annual economic damages are estimated to be in the order of $200 million. Of these damages, over 70 per cent occurred in southwestern Ontario. The average transboundary contribution is over 80 per cent of these damages or in the range of $165 million per year. In southwestern Ontario, the transboundary contribution is over 85 per cent of the local agricultural crop damages.

Table 4.7: Economic Losses Due to Agricultural Crop Damages

	Attributable Economic Losses ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**0.0**	**0.1**	**0.1**
Central Ontario	**0.3**	**0.6**	**0.9**
Southeast Ontario	**5.1**	**9.9**	**15..0**
South Central Ontario	**10.8**	**30.0**	**40.8**
Southwest Ontario	**19.9**	**124.4**	**144.3**
Total	**36.1**	**165.0**	**201.1**

4.2.4.2 Forest Productivity Damages

The vulnerabilities of forest ecosystems to air pollution impacts are similar in concept to those associated with agricultural crops. However, there are some significant differences. The effects of foliar damage are generally not addressed as a separate air pollution response function. Some of these impingement effects may be captured by soil acidification/change in productivity measurements. These measurements have been used to derive soil acidification concentration response functions.

Scientific understanding of the basic causal relationships between air pollution and forest ecosystem impacts has advanced considerably over the last several decades; but, this understanding has not been applied in such a way that the precision of physical and economic damage forecasts has improved substantially. As a result, estimating forest productivity damages involves considerable uncertainty.

A detailed breakdown of annual yield from Crown forests is available for each Ontario forest region (OMNR, 2004). These yield estimates are broken down by major wood types (i.e., three conifer and three hardwood wood types).

Productivity losses were estimated by applying measured losses by tree type (Quimet et al, 2001) to the corresponding estimated wood yields. High and low ranges were derived using the reported statistical error ranges.

Once the total damages had been estimated, the Ontario and transboundary proportion were estimated. It was assumed that the damages were directly proportional to the relative Ontario and transboundary contributions to ozone and $PM_{2.5}$.

The monetary value of the estimate physical losses of wood is difficult to estimate for several reasons Ontario charges stumpage fees for all wood harvested on Crown land. These fees vary by wood type and quality (i.e., final use). Stumpage is the rent that the public realizes for wood grown on Crown land. As such, stumpage represents only a portion of the full value of the wood. The additional value is realized by the logging, transportation, wood processing/manufacturing and retailing components of the forest products industry. This additional value of the wood is not captured in the damage estimates included in this study.

Forest Productivity – Physical Damages

Table 4.8 presents a summary of the physical losses in wood yield attributable to air pollution. The losses are broken down by forest management region and by land ownership (i.e., Crown and private). The low, central and high estimates reflect the ranges in the damage function.

Table 4.8: Summary of Estimated Wood Losses by Landownership Category

	Estimated Wood Losses (Mm^3/a)			
Ownership	**Low**	**Central**	**High**	**Percent Loss[a]**
NE - Crown	**3**	**6**	**10**	**29%**
NE - Private	**0.2**	**0.3**	**0.4**	**23%**
NE - Total	**3.2**	**6.3**	**10.4**	**29%**
S - Crown	**0.5**	**0.7**	**1**	**36%**
S - Private	**0.5**	**0.7**	**0.8**	**27%**
S - Total	**1**	**1.4**	**1.8**	**31%**
Overall Total	**4.2**	**7.7**	**12.2**	**29%**

a: Percent loss is expressed as a proportion of the current yield plus damages.

Table 4.9 provides the distribution of these damages between Ontario and transboundary sources of air pollution.

In both the Northeast and Southern Regions, damages attributable to transboundary air pollution are about double those associated with Ontario emissions of air pollutants. These proportions are reasonably constant over the range of estimated physical damages.

Table 4.9: Attributable Forest Productivity Damages

	Attributable Forest Productivity Damages (Mm^3/a)		
	Ontario	**Transboundary**	**Total**
NE Region	**2**	**4**	**6**
S Region	**0.5**	**1**	**1.5**
Total	**2.5**	**5**	**7.5**

Forest Productivity – Economic Damages

The monetary damages corresponding to these physical damages were estimated using the corresponding stumpage fees. Table 4.10 provides a summary of the resulting monetary damage estimates. These estimates are the average of the damages using the low and high stumpage fees.

Table 4.10: Economic Losses Due to Forest Productivity Damages

	Attributable Economic Losses ($Millions/a)		
	Ontario	**Transboundary**	**Total**
NE Region	**18.7**	**36.9**	**55.6**
S Region	**7.8**	**14.4**	**22.2**
Total	**26.5**	**51.3**	**77.8**

Overall air pollution is estimated to be causing in northeastern and southern Ontario about $77 million in damages each year. The majority of the damage is occurring in the northern portions of the province. This is an area of the province where the local economy depends heavily on the forest products industry.

Of this total damage, approximately $51 million is attributable to transboundary air pollution. In other words, businesses and individuals outside of the province in effect are "harvesting" in the order of $51 million worth of timber without having to pay anything to the people of the province.

4.2.4.3 Damages to Buildings and Structures

The acid fraction of PM, SO_2 and ozone damage different types of exterior materials and coatings at different rates. The rate of damage is also dependent on metereological conditions and the direction and angle of exposure of materials and coatings.

Environment Canada has produced forecasts of the inventory of Canadian building materials and a breakdown of their exposed surface area by material type. The inventory is designed to be used with damage functions similar to those developed by the ICP Materials program based at the Swedish Corrosion Institute. Environment Canada's exposed materials inventory was used in this study. A detailed explanation of the contents and sources for the data in the dataset has been prepared [Law and Economics Consulting Group (LECG), 2003].

Considerable modification of the dataset was required to make the contents compatible with the damage function methodology used in this analysis. However, the basic connections between the inventory and population growth and economic production were maintained. The amount and type of exposed materials from schools, dwellings, and power lines were forecast as a function of population growth. As the population expands, so too does the inventory of exposed materials. The population data used for other damage functions in this analysis were used also to estimate the inventory of exposed materials. The amount and type of exposed materials from industry, offices, and shops were based on GDP growth. The 2003 GDP statistics were used to estimate this portion of the inventory.

Two air pollution parameters were required for these damage functions. Ambient concentrations of SO_2 had been estimated as part of a project for the Ontario Medical Association (DSS, 2005). Rainfall pH (i.e., H^+ concentrations) was estimated from work by Environment Canada. The centroids of each CD were located and the resulting rainfall pH interpolated. A background rainfall pH of 5.6 was assumed.

Average relative humidity and temperature for each CD were derived from Environment Canada meteorological records (http://www.climate.weatheroffice.ec.gc.ca/climateData/). Records for 2003 were used since this was the latest year for which complete records were available.

Separate materials damage rates were calculated for Ontario and transboundary air pollution by using the corresponding air pollution proportions. In the case of rainfall pH, the proportions of $PM_{2.5}$ were used to approximate the H^+ concentration proportions.

The monetisation methodology used for materials damages is based on the assumption that damages to materials caused by air pollution will be repaired periodically. In other words, the value of the damages is the increased level of repair and maintenance, above and beyond that which would normally occur in the absence of air pollution.

Buildings and Structures – Economic Damages

Table 4.11 presents the estimated economic damages associated with materials damage in Ontario in 2003. Total damages amount to about $1 billion per year. Most of this damage is associated with south central Ontario where the highest concentration of materials and buildings is found. Of this total, transboundary air pollution accounts for about one third or about $300 million per year.

Table 4.11: Economic Losses Due to Materials Corrosion/Deterioration

	Attributable Materials Damages ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**31**	**10**	**41**
Central Ontario	**23**	**7**	**30**
Southeast Ontario	**97**	**21**	**118**
South Central Ontario	**457**	**148**	**605**
Southwest Ontario	**57**	**124**	**181**
Total	**665**	**310**	**975**

4.2.4.4 Visibility Damages

Visibility impacts are largely an aesthetic issue but impairment of aesthetic values result in social welfare losses in much the same way as losses are suffered when other non-marketed environmental goods and services are degraded.

The Canadian Environmental Protection Act (CEPA) (1999) has developed a function to estimate visibility impairment caused by $PM_{2.5}$. $PM_{2.5}$ causes reduction in visibility when the particles reflect the light causing distant images to blur and ultimately as concentrations increase, to become invisible. The reduction in visibility range was calculated using the total anthropogenic $PM_{2.5}$. The proportion of this reduction attributable to Ontario emissions was calculated using the Ontario contribution to total anthropogenic $PM_{2.5}$.

The impact of visibility impairment is highly dependent on the values and preferences of the individual. Economists have developed specialized techniques to compute the value that people place on environmental attributes like visibility. Haider et al. (2002) designed a contingent choice (CC) survey that was administered to a reasonably representative group of individuals from the Lower Mainland of British Columbia. The results of the survey were used to derive economic value functions for estimating the economic damages associated with reduced visibility.

Visibility – Economic Damages

Table 4.12 presents the estimated economic damages associated with reduced visibility caused by air pollution. The total annual damages are estimated to be around $1.3 billion. This value may at first sound high but this damage estimate is in line with similar damage estimates prepared for other jurisdictions and using methodologies other than the one used in this study. Certainly, the sight of 'dirty air' is suffered by everyone when air pollution is high. Figures 4.3 and 4.4 illustrate the reduced visibility during smoggy days observed in Toronto, Ontario compared to that of a clear day.

Transboundary air pollution accounts for about 60 per cent of the total visibility damages. Not surprisingly, these damages are greatest in the southern part of the province.

Table 4.12: Economic Losses Due to Visibility Reduction

	Attributable Economic Losses ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**8**	**23**	**31**
Central Ontario	**6**	**27**	**33**
Southeast Ontario	**50**	**138**	**188**
South Central Ontario	**435**	**350**	**785**
Southwest Ontario	**39**	**241**	**280**
Total	**538**	**779**	**1,317**

Figure 4.3: Clear Day in Toronto, Ontario on August 12, 2001.
(Photo: Courtesy of Jeff Brook – Environment Canada)

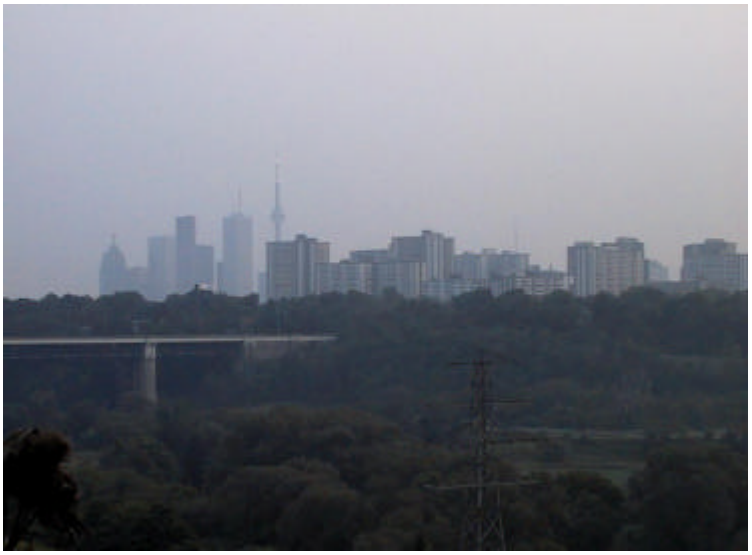


Figure 4.4: Smoggy Day in Toronto, Ontario on August 30, 2001.
(Photo: Courtesy of Jeff Brook – Environment Canada)

4.2.4.5 Materials Soiling Damage

This materials soiling damage function is based on the number of households in each CD and the concentration of particulate matter, more specifically, PM_{10}[28]. The basic underlying assumption is that the amount of sensitive receptor (i.e., household materials) exposed to pollution is directly proportional to the number of households. The 2001 census population data were used to estimate the numbers of households in each CD.

Materials Soiling – Economic Damages

The estimated materials soiling damages are shown in Table 4.13. Total annual damages in Ontario from air pollution soiling household materials are estimated to be $427 million. Most of this damage occurs where the population is concentrated (i.e., south central Ontario which includes the Greater Toronto Area and other major population centers in the Golden Horseshoe).

Table 4.13: Economic Losses Due to Materials Soiling

	Attributable Soiling Damages ($Millions/a)		
	Ontario	**Transboundary**	**Total**
Northeast Ontario	**3**	**6**	**9**
Central Ontario	**3**	**6**	**9**
Southeast Ontario	**15**	**27**	**42**
South Central Ontario	**143**	**127**	**270**
Southwest Ontario	**25**	**72**	**97**
Total[a]	**189**	**238**	**427**

[28] A one-to-one correspondence between $PM_{2.5}$ and PM_{10} has been assumed for the purposes of estimating these damages. This assumption underestimates these damages; however, much of the transboundary air pollution in Ontario is the finer $PM_{2.5}$ fraction and not the coarser PM_{10}. As a result, the transboundary damages are likely to be closer to the true damages.

Ontario emissions account for $189 million of these damages; whereas, transboundary air pollution accounts for about $238 million or about 56 per cent of the total damages. The Ontario and transboundary proportions vary significantly from one region of the province to another. In all regions of the province except south central Ontario (where 47 per cent of the damages are attributable to transboundary air pollution), transboundary air pollution accounts for the majority of the soiling damages. In southwestern Ontario, transboundary air pollution accounts for almost 75 per cent of the damages.

4.2.4.6 Aquatic Ecosystem Damages

Long-range transport of air pollution first gained a high public profile when negative impacts on aquatic ecosystems were discovered. Transboundary air pollution was recognised as a major contributor to these acidification impacts. Despite over three decades of intensive research on these impacts, no systematic and comprehensive methodology is in place to estimate these damages in terms useful for economic valuation.

A major barrier to estimating economic damages is the highly site-specific nature of the load-response functions exhibited by individual waterbodies and watersheds. Furthermore, linking acidification to changes in valued aquatic resources (e.g., sportfish productivity) has remained highly site-specific and complex.

For these reasons, estimates of the physical and economic damages associated with aquatic ecosystem impacts of air pollution have not been included in this analysis. Estimates from previous studies (e.g., Victor & Burrell, 1984) suggest that these impacts could be quite significant in both physical and economic terms.

Other Air Pollutants

Long-range transport of air pollution is not limited to only $PM_{2.5}$ and ozone. Many other inorganic and organic pollutants are known to be transported long distances from one jurisdiction to another. These pollutants impact human health and environmental resources.

This analysis is limited to the impacts of PM, ozone and associated chemicals. Estimating the impacts of these pollutants is challenging despite years of intensive research on their environmental behaviour and effects. No comparable knowledge base is available to develop quantitative impacts of the other pollutants. What can be concluded is that since these pollutants and their impacts are not included in this analysis, the damage estimates presented in this report likely underestimate the total damages of air pollution in Ontario.

5.0 Emission Control Programs, Initiatives and Agreements in Ontario, Canada and the United States

In response to the threats posed by smog, acid rain and hazardous air contaminants transboundary air pollution in eastern North America, over the past three decades Ontario, Canada and the U.S. have acted to mitigate known and/or suspected adverse effects on the environment and the population. This chapter highlights key actions taken by these jurisdictions on emission control programs, initiatives, cooperative efforts and bi-national agreements to address the challenges at hand, with emphasis on their most recent actions and those under consideration.

5.1 Ontario's Action

Ontario's approach to reducing smog addresses the diversity of emission sources that lead to the formation of smog in Ontario from both local and transboundary pollution. The government is following a multi-faceted, comprehensive smog reduction approach that addresses multiple pollutants (some of which are common to smog and acid rain), provides encouragement to all sectors of the economy, and targets key emission sectors such as electricity generation, transportation, industry and residential.

The government's key smog-causing emission reduction activities can be grouped into the following eight categories: (1) Regulatory initiatives; (2) Government leadership; (3) Conservation; (4) Clean energy incentives; (5) Public education and outreach; (6) Encouraging non-regulatory commitments; (7) Building capacity; and (8) Agreements between Ontario and other provincial/state jurisdictions. Ontario has a long history of encouraging the federal government to take action where federal emission reduction tools would be most efficient, and to initiate discussions with the U.S. on transboundary anti-smog actions when necessary and appropriate.

In June 2004, the government released *Ontario's Clean Air Action Plan* (CAAP)[29] at the Smog Summit in Toronto. The CAAP is a roll-up of Ontario's initiatives to improve air quality in the province. The CAAP provides background information on smog, explains the need for action, outlines Ontario's smog reduction targets, and describes Ontario's smog reduction approach. It also includes current and proposed initiatives such as the commitment to close coal-fired generation in Ontario by replacing them with cleaner sources of power.

5.1.1 Key Regulatory Initiatives

As part of its commitment to clean up Ontario's air, on June 21, 2004 the government announced a five-point action plan to reduce industrial emissions of harmful air

[29] *Ontario's Clean Air Action Plan* is available from the Ontario Ministry of the Environment website http://www.ene.gov.on.ca/programs/4708e.htm

pollutants. Reducing industrial emissions complements the programs Ontario already has in place to reduce air pollution created by the transportation and electricity sectors.

The plan includes:

1. Applying tough nitrogen oxide (NO_x) and sulphur dioxide (SO_2) limits -- two of the most significant smog-causing pollutants -- to more industrial sectors than ever before.
2. Making the NO_x and SO_2 limits even stricter in future years.
3. Setting tough new air standards, in some cases for the first time, for 29 harmful pollutants, including carcinogens and toxins that could pose a threat to human health.
4. Achieving a better picture of industrial emissions through updated technology.
5. A faster, risk-based approach to implementing new air standards.

The Industry Emission Reduction Plan (ERP) is part of the five-point action plan outlined in June 2004. It presents the elements of a proposed regulation which would establish NO_x and SO_2 industry sector emission caps for the years 2006, 2007-2009, 2010-2014 and 2015 and onward, as well as budgets for each sub-sector and allowance allocations for each facility within each sub-sector. The plan outlines the distribution of NO_x and SO_2 allowances to facilities including the provisions for existing facilities that expand or rebuild, new facilities and facilities that close down or experience partial or temporary shut-down. The proposal also integrates the emission caps with the emission trading system and the electricity sector regulation (O. Reg. 397/01). In February 2005, the Ministry of the Environment proposed a draft regulation that built upon the Industry ERP.

In May 2005, the Ministry of the Environment finalized a regulation (O.Reg. 194/05) that was built upon the Industry ERP. Under the regulation, emissions of NO_x from five industrial sub-sectors, which account for 10 per cent of total provincial NO_x emissions, would be capped at 21 per cent below their 1990 levels. Emission of SO_2 from six sub-sectors, which account for 61 per cent of total provincial SO_2 emissions, would be capped at 46 per cent below 1994 levels.

The province has in place a regulation (O. Reg. 397/01) that establishes annual caps with respect to NO_x and SO_2 emissions from Ontario Power Generation's (OPG) fossil fuel power plants and the electricity sector. Under Ontario Regulation 396/01, the coal-fired Lakeview Generating Station in Mississauga ceased burning coal by April 30, 2005. In addition, Ontario's Guideline A-9 imposes a NO_x emission limit on new or modified large boilers and heaters in industrial installations.

Through Orders under Ontario's Environmental Protection Act, Inco Ltd. and Falconbridge Ltd. are required to reduce their allowable annual SO_2 emissions from their smelting operations in the City of Greater Sudbury by 34 per cent, effective in 2007.

To reduce air emissions from the transportation sector, Ontario launched its *Drive Clean* Program (O. Reg. 361/98) in 1999, which requires vehicle emission inspection and

maintenance for over 5.5 million light-duty and heavy-duty vehicles registered in Ontario. For light duty vehicles (LDVs) registered in the southern Ontario smog zone, it was estimated that *Drive Clean* reduced smog-causing emissions by more than 81,200 tonnes between 1999 to 2003. In addition, emissions of carbon monoxide (CO) and carbon dioxide (CO_2) were reduced by over 690,000 tonnes and more than 100,000 tonnes, respectively, due to *Drive Clean* during this period.

From January 1, 2000 to December 31, 2002, the Heavy Duty Vehicle component of the *Drive Clean* program reduced particulate matter by nearly 1,100 tonnes. In April 2004, *Drive Clean* implemented among the most stringent emissions standards in North America for heavy duty diesel vehicles. Diesel school buses are required to meet the more stringent of these standards to help protect children's health. On April 1, 2005, these emissions standards were further tightened.

With respect to enforcement, Ontario's Smog Patrol supports the *Drive Clean* Program by inspecting trucks, buses and light-duty vehicles suspected of emitting excessive exhaust smoke or of having emissions control equipment that has been tampered with or removed. The Smog Patrol inspects vehicles that are registered in Ontario as well as vehicles registered in other jurisdictions. Since 1998, the Smog Patrol has conducted over 38,000 vehicle inspections and issued more than 6,200 tickets.

To meet the remaining three goals of the five-point plan related to the reduction of harmful industrial pollutants, Ontario is developing a comprehensive Air Pollution regulation which would revoke and replace the existing 30-year old regulation (Ontario Regulation 346). This new regulation would implement new air standards that will protect Ontario communities from the impacts of air pollution. A draft regulation was posted on the Environmental Bill of Rights Registry in May 2005 for a 30-day consultation.

5.1.2 Examples of Government Leadership

The Government of Ontario and the Government of Canada signed a Memorandum of Understanding for Cooperation on Addressing Climate Change in May 2004. Priority areas for cooperation are electricity supply and renewables; energy efficiency, conservation and fuels; environmental management; innovation and technology; land resources and agriculture; impacts and adaptation; and public awareness and education. Joint actions in many of these areas will have benefits for both air quality and climate change.

The Government of Ontario, along with the Government of Canada and the City of Toronto, announced a $1 billion funding package in March 2004 representing the largest ever joint federal-provincial investment in municipal transit. This agreement will provide an average of $70 million per year from each government over five years to improve, modernize and expand the Toronto Transit Commission (TTC) system and help provide better transit service to the TTC's 1.3 million daily riders.

The Ontario government was authorized to establish the greenbelt area and plan by the Greenbelt Act which became law on February 24, 2005. The greenbelt plan identifies where urbanization should not occur and will permanently protect more than one million acres in the Greater Golden Horseshoe from urban sprawl. A proposed Growth Plan linked to the Greenbelt will identify how the lands surrounding the Greenbelt will be used, and will manage the expected population and employment growth in the Greater Golden Horseshoe. The proposed plan will also guide everyday land use decisions that support more intensification/redevelopment, coordinate infrastructure and transportation needs which will positively affects air quality.

The Ontario government encourages the use of cleaner fuels in the transportation sector. It has contracted for the purchase of ethanol-blended gasoline to power its vehicle fleets. For example in 2004, approximately 9 per cent of the fuels purchased (1.5 million litres) for the Ontario Public Service (OPS) fleet were ethanol-blended fuels.

Ontario currently has in place a $0.147 per litre ethanol tax exemption and a $0.143 per litre bio-diesel tax exemption as support of its commitment of requiring that "ethanol make up 5 per cent of gasoline by 2007 and 10 per cent by 2010" and its commitment to the "development of an Ontario bio-based strategy that will include mandatory bio-diesel content in diesel fuel". GO Transit has moved to the use of low-sulphur diesel fuels year-round in its bus fleet. During the traditional smog season from May to September, the rail fleet also uses low-sulphur diesel fuels.

Ontario also continues to purchase new hybrid vehicles which reduce air pollution through improved efficiency. As of April 2005, of the 6,000 passenger vehicles in the OPS fleet, 44 are hybrids and of these, 20 are used by the Ministry of the Environment.

Ontario's Smog Alert Response Program (SARP) promotes strategies for municipalities and the Ontario Public Service (OPS) to develop/adopt for the protection of the environment and human health during smog alerts.

5.1.3 Conservation and Recent Partnership Projects

In April 2004, the Premier of Ontario set a target of reducing the province's energy consumption by five per cent by 2007, as part of his government's plan to create an energy conservation culture throughout the province. The conservation plan includes: creating an Ontario Power Authority that will include a Conservation Secretariat led by a Chief Conservation Officer; launching a public education and outreach campaign to encourage conservation; setting aggressive targets to put smart meters into households; and developing regulations to provide province-wide access to net metering, which enables homeowners and businesses generating renewable electricity to receive credit for the excess energy they produce. In order to lead by example, Premier McGuinty has asked the provincial government to reduce its own electricity consumption by 10 per cent by 2007.

In November 2003, the government enabled LDCs (Local Distribution Companies) to achieve their full commercial rate of return on the condition they invest an amount equivalent to one year's worth of these monies (approximately $225 million) in conservation and demand management initiatives. To date 80 of the provinces 90 LDCs have received approval for $160 million in conservation funding and are putting programs in place. This regulatory framework for conservation and demand side management for electricity distribution companies is similar to the framework put in place for natural gas distributors in 1995.

The government has also established a number of strategic partnerships to encourage long term sustainable approaches to conservation in a variety of sectors. Examples include the following:

Low Income/Social Housing Sector

Under Social Housing Energy Management (Social Housing Service Corporation), an initial program was developed to establish a pilot project with 20 social housing complexes and co-operatives across the province that will lead to centralized energy management services for 1,500 social housing providers representing over 250,000 units of non-profit, municipally-owned or co-operative housing.

The Low-Income DSM (Demand Side Management) Strategies for LDCs (Canadian Environmental Law Association) developed a set of proposed DSM initiatives that could be undertaken by LDCs to assist low-income households in reducing electricity consumption and costs.

Schools and Colleges

EcoSchools (York University) developed an innovative conservation outreach initiative targeted at schools with a focus on both simple operational improvements to conserve energy and reduce waste, backed up by teaching materials on conservation for students.

The Ontario Colleges Efficiency Project (Association of Applied Arts and Training Ontario) developed a prioritized needs assessment for energy efficiency capital retrofits at Ontario's public colleges.

Sustainable Schools (Toronto Region Conservation Authority) developed energy performance baselines for 20 York Region schools for the purpose of demonstrating how GTA school boards could improve energy performance and savings through better school design.

Industry, Agricultural and Small Business

The On-Farm Energy Audit Pilot (OMAF, OFA, Hydro One) was developed as a pilot energy audit program for farms.

Cool Shops (Clean Air Foundation) developed a plan for replication of this retail sector conservation outreach program in 3 communities outside of Toronto including London, Ottawa and Peterborough.

DSM Survey of the Industrial Sector (AMPCO - Association of Major Power Consumers Ontario) surveyed 30 to 40 AMPCO and CME (Canadian Manufacturers and Exporters) member organizations to determine the Demand Side Management/Demand Response (DSM/DR) needs of industrial electricity users.

Health Care Sector
The Ontario Hospitals Association delivered the Green Health Care program to promote energy efficiency and environmental responsibility in the health care field across Ontario.

The Toronto and Region Conservation Authority (TRCA) developed energy performance benchmarks for the Greening Health Care program for hospitals within the Greater Toronto Area (GTA).

Buildings
EnergyStar for New Homes (EnerQuality Corporation) developed an Energy Star labelling program for new homes to be piloted in Ontario. The program can work in tandem with the Federal government's Energuide for New Homes label. The program identifies new homes which have higher energy performance.

Residential
20/20 - The Way to Clean Air (Toronto Public Health) was a program that provides residents with a conservation planner to help build an energy conservation program at home.

5.1.4 Key Clean Energy Initiatives

Coal stations are major sources of air emissions and the Government of Ontario is committed to developing cleaner energy sources to replace coal-fired generation in Ontario. Replacing coal stations with cleaner generation provides dual benefits for a healthier Ontario by reducing smog and acid rain causing emissions and reducing climate change causing greenhouse gas emissions. Ontario closed the Lakeview Generating Station in April of 2005 and has developed a plan to phase out the four remaining plants to replace the 7500 MW of coal fired capacity.

The government has launched numerous initiatives for new, cleaner generation:

1. Work has begun on the expansion of the Beck Tunnel to increase the capacity of the massive hydraulic generation plant at Niagara Falls.

2. On September 30, 2004 the governments of Manitoba and Ontario announced they would proceed with a detailed technical study on the Clean Energy Transfer Initiative (CETI), a proposed hydroelectric power project in Northern Manitoba (Conawapa Dam on the Nelson River) and a transmission line that would bring power from Manitoba to Ontario.

3. On November 24, 2004, the government announced approval for 10 projects in response to the Request for Proposals (RFP) for 300 MW of new renewable energy

capacity. The projects include two waterpower projects, three landfill gas projects and five wind farms for a total of 395 MW of clean, renewable energy.

4. On March 21, 2005, Energy Minister Dwight Duncan announced that the government's negotiator had completed its work and reached a tentative agreement with Bruce Power for the restart of the remaining two units at Bruce Power's nuclear facility in Kincardine. The potential restart of Units 1 and 2 at the Bruce facility would result in an additional 1,540 megawatts of electricity generating capacity, which is enough to power over one million homes across Ontario. Restarting these units would also potentially replace over 20 per cent of Ontario's current coal capacity and related harmful emissions.

5. On March 30, 2005, Energy Minister Dwight Duncan announced that the Ontario government had submitted a joint proposal with Hydro-Québec and SNC-Lavalin to support Newfoundland and Labrador in the development of a major hydroelectric generation project at the Lower Churchill River in Labrador. The proposed project would yield 2,824 megawatts of clean, affordable and sustainable electricity. Ontario would receive one-third of the total output of the project. As part of the agreement, Hydro-Québec would also advance construction of a 1,250 megawatt interconnection with Ontario, to be in service by 2009.

6. Early in 2005, the government posted new regulations to provide province-wide access to net metering, which enables homeowners, farms and businesses generating renewable electricity to receive credit for the excess energy they produce.

7. On April 13, 2005, the government announced four new electricity projects, including a cogeneration project, a demand response project, and two new combined-cycle natural gas-fired generating plants. These projects have a combined capacity of 1,675 megawatts, and will bring an estimated $1.1 billion of new capital investment to Ontario.

8. On April 19, 2005, the government announced it would boost Ontario's supply of renewable energy with the release of a Request for Proposals (RFP) for up to 1,000 megawatts of clean, green, renewable power.

9. Ontario offers a sales tax rebate for solar energy systems incorporated into residential premises after November 25, 2002, and before November 26, 2007. It also has a sales tax rebate program for vehicles powered by alternative fuels, up to a $1,000 limit. Producers of clean power enjoy tax advantages if they contribute to the province’s supply of green power before January 1, 2008.

10. The government has also clarified the mandate on Ontario Power Generation which will focus on renewing existing and developing new hydraulic generation sites across Ontario.

5.1.5 Public Education and Outreach

The OnAIR program found through www.ene.gov.on.ca gives the public broad access to more information on air pollution in a timely manner. The associated regulation "Airborne Contaminant Discharge – Monitoring and Reporting" (O.Reg. 127/01) requires selected electricity, industrial, commercial, institutional and municipal facilities in Ontario to report on over 350 air contaminants, including emissions of primary particulate and smog precursors (e.g., NO_x, SO_2, and VOCs) and the main greenhouse gases. The ministry's air quality Web site www.airqualityontario.com provides near-real time reporting of air quality monitoring information for 38 air quality index sites across Ontario. Smog forecasts are also provided for 37 regions.

In 2005, Ontario's Climate Air Connections Hub was launched, in partnership with Environment Canada and the Clean Air Foundation. The hub works to help extend Ontario public education and outreach programs, so more Ontarians can have access to air quality and climate change information.

5.1.6 Encouraging Non-Regulatory Commitments

Ontario's industries need to play a prominent role if emission reduction efforts are to be successful. One way industry can do this is through non-regulatory commitments. For example, through the Anti-Smog Action Plan (ASAP) program, many of Ontario's industries have developed non-regulatory commitments and/or are implementing measures to reduce smog precursors. Sub-sectors such as non-ferrous smelters, electricity, iron and steel, cement, chemical, automobile manufacturing and petroleum refineries are taking voluntary actions to reduce NO_x, SO_2, and VOCs. A detailed summary of non-regulatory commitments made through the ASAP program can be found in Ontario's Anti-Smog Action Plan: Progress Through Partnership, available at http://www.ene. gov.on.ca/envision/air/smog/asap2002.htm

5.1.7 Building Scientific Capacity

Scientific capacity building continues to be a key component of Ontario's smog reduction approach. Ontario recognizes that more needs to be done, and specific knowledge gaps need to be filled. For example, the province needs to improve its emissions inventories and scientific understanding of health impacts. Since 1995, Ontario has invested more than $5 million to establish one of the most modern and best-equipped air monitoring networks in North America. Currently, there are 38 state-of-the-art Air Quality Index (AQI) monitoring stations located across Ontario. Real-time data gathered from the network are used to publish Ontario's Air Quality Index and issue Smog Watches and Advisories.

Work continues in implementing and refining mathematical air pollution dispersion models which provide valuable insights into the relationships between precursor emissions, ambient pollutant concentrations (e.g., CMAQ state-of-the-art particulate matter and ozone modelling system originally developed by the U.S. EPA and now used

worldwide) and the deposition of acidic and toxic (e.g., mercury) substances. Such air quality models are the best tools currently available for determining necessary emission reductions, and where these reductions should take place, for example, in promoting compliance with the CWSs for $PM_{2.5}$ and O_3.

Scientific capacity building is also partnerships building. Through the *Best in Science* program, Ontario is engaging the research community to help identify and bridge science knowledge gaps.

The *Best in Science* program was established in 2004 to strengthen and showcase the ministry's scientific capacity. The program is effective in contributing to healthier communities and ecosystems through sponsorship of innovative, sound scientific research that supports the government's priorities, through collaborative partnerships with leading research communities. Continued support for this program will help reposition the Ontario Ministry of the Environment at the forefront of environmental protection.

The *Best in Science* program has engaged the research community by establishing a number of collaborative projects and agreements with universities, research networks and other science-based organizations. To date, fifteen projects are underway, supported by the ministry both financially and with in-kind support. At least three of those projects are related to research on the environmental effects and behaviour of air pollutants.

5.1.8 Agreements Between Ontario and Other Provincial/State Jurisdictions

Ontario has long recognized the importance of working with its neighbours to reduce transboundary air pollution across the region. As early as in the 1970s and 1980s, the province signed Memoranda of Understanding (MOU) with a number of U.S. states to address this issue. They are briefly summarized below:

5.1.8.1 Ontario and Quebec

Ontario shares one of its longest borders with Quebec. Both provinces may be potentially affected by transboundary environmental problems, as they share the same transboundary air flows and responsibility for the largest freshwater system in the world, the Great Lakes – St. Lawrence Basin.

In 1988, the Premiers and Ministers of the Environment from Ontario and Quebec signed an "Agreement of Environmental Cooperation between la Province du Québec and the Province of Ontario". The purpose of the agreement was to establish systems of dialogue, and concerted, cooperative efforts in regard to the environmental protection problems of joint concern to Quebec and Ontario especially in relation to polluting materials released directly or indirectly into the environment. The jurisdictions engaged each other on a case-by-case basis.

Ontario and Quebec are currently working on a renewed cooperation agreement concerning transboundary environmental impacts. The purpose of the renewed

agreement is to encourage information sharing, mutual understanding and cooperation on transboundary issues including, but not limited to, air quality and atmospheric pollutants; surface and groundwater management, monitoring and reduction of pollution in rivers, lakes and waterways; protecting, conserving and restoring the natural environment; and Great Lakes - St. Lawrence watershed issues. The renewed agreement will reinstitute formal arrangements for the sharing of information and expertise, as well as establish closer cooperation on environmental initiatives between the two provinces.

In addition to the agreements, Ontario and Quebec cooperate on various initiatives. For instance, Ontario and Quebec coordinate their smog activities for the Ottawa-Gatineau areas when smog levels are expected to be elevated. Indirectly, Ontario works with Quebec vis-à-vis the NAPS (National Air Pollution Surveillance) Agreement on air quality monitoring activities, an agreement signed by the provinces and territories and the federal government. Ontario also participates with Quebec and neighbouring U.S. states in the EPA's AIRNOW real time air quality mapping program.

5.1.8.2 Ontario and Michigan

Ontario and Michigan have a long record of cooperation on air quality issues. In December 1974, Michigan and Ontario entered into an MOU to implement air pollution control programs in the Southwestern Ontario - Southeastern Michigan regions to achieve air quality objectives recommended by the International Joint Commission (IJC). The Ontario - Michigan Letter of Intent on Shared Areas of Concern is a companion agreement to The Ontario - Michigan Letter of Intent on Environmental Quality.

The MOU on Transboundary Air Pollution Control between the Province of Ontario (Ministry of the Environment) and the State of Michigan (Michigan Department of Environmental Quality) was signed at the same time as the Ontario – Michigan Letter of Intent on Environmental Quality in December 1985. The purpose of the MOU is to update the1974 MOU and to strengthen cooperation between the two jurisdictions on air quality management including: surveillance and monitoring; emission source inventory; exchange of information on air quality standards; implementation of control programs and provision for joint studies.

Since May 2000, meteorological and air quality discussions between Michigan and Ontario meteorologists have occurred on a weekly basis (and sometimes daily if necessary) during the traditional smog season. This arrangement expanded in 2004 to also include year round discussions under LADCO (Lake Michigan Air Director's Consortium) on the issuance and harmonizing of smog alerts and ozone action days, as well as $PM_{2.5}$ forecasting in the Great Lakes transboundary area.

5.1.8.3 Ontario and Minnesota

The Ontario Ministers of the Environment and Intergovernmental Affairs and the Executive Director of the Minnesota Pollution Control Agency signed the MOU on "Co-operation in Combating Acidification Between the Province of Ontario and the State of

Minnesota" in August 1983. The purpose of the MOU is to foster understanding of the effects of acid precipitation, share scientific information and technical expertise regarding emission inventories, and collaborate on joint studies regarding the modelling of long-range transport and the development of abatement strategies.

5.1.8.4 Ontario and New York

Both Ontario and New York share a common interest in the battle against upwind sources of air pollution, since the environment and health of citizens and sensitive aquatic ecosystems in both Ontario and upper New York State continue to be impacted by acid precipitation and transboundary air pollution, primarily from mid-west states in the U.S.

In April 1983, Ontario's Intergovernmental Affairs Minister and the Minister of the Environment and the Commissioner of the New York State Department of Environmental Conservation signed an MOU on "Cooperation in Combating the Effects of Acidification Between The Province of Ontario and the State of New York". The Commissioner of the New York State Department of Environmental Conservation and Ontario's Minister of the Environment signed an MOU in February and April 1999, respectively, on "Combating the Effects of Transboundary Air Pollution" to ensure coordination of efforts in Ontario and New York to combat the effects of acid precipitation. It provides for data compatibility; ensuring that emission control programs meet goals in their own jurisdiction; and establishing a Joint Committee to develop work plans and progress reports to implement the agreement and provide for information exchanges.

Staff of the MOE and the New York Department of Environmental Conservation have undertaken collaborative scientific analyses under the terms of the Ontario-New York agreement. This work has culminated in the publication of scientific journal articles and presentations at scientific conferences describing atmospheric ozone and fine particulate matter.

5.1.8.5 Ontario and Ohio

Ontario and the state of Ohio share a common interest in the reduction of air pollution caused by coal-fired power plants. Ontario has committed to shut down the province's five coal-fired plants. Ohio has implemented more stringent standards for these emissions and is currently putting in place a plan that will force significant reductions in coal-fired generating plant emissions. The province plans to work together with Ohio through the sharing of scientific and policy knowledge.

5.2 Canada's Action

Ontario continues to work closely with the Canadian federal government to encourage the use of appropriate federal tools in reducing emissions affecting Ontario's air quality and addressing transboundary air issues through bi-national agreements such as the 1991 Canada-U.S. Air Quality Agreement. The federal government plays a key role by taking

the lead in mandating cleaner vehicles and fuels and developing action plans to address greenhouse gas (GHG) emissions, and VOC emissions from consumer and commercial products on a national scale.

5.2.1 Cleaner Vehicle Engines and Fuels

It is expected that national measures to lower emissions from vehicles, engines and fuels, both on-road and off-road, will produce significant reductions in mobile source emissions. Current initiatives include:

a) the Sulphur in Gasoline Regulations, which became effective January 1, 2005, will limit the amount of sulphur in gasoline throughout Canada to an average level of 30 ppm (parts per million),

b) the Sulphur in Diesel Fuel Regulations will limit sulphur levels in diesel fuel used in on-road vehicles to a maximum of 15 ppm, starting in mid-2006.

c) the On-Road Vehicle and Engine Emission Regulations phase in more stringent emission standards for on-road vehicles and engines, beginning with the 2004 model year. The regulations apply to light-duty vehicles (i.e., passenger cars), light-duty trucks (i.e., minivans, pick-up trucks, sport utility vehicles), heavy-duty vehicles (i.e., trucks, buses), heavy-duty engines and motorcycles.

d) the development of standards, aligned with those of the U.S. EPA, to deal with small and large spark-ignition engines, off-road diesel engines, recreational marine engines and off-road recreational vehicles.

These stricter vehicle and engine emission standards and the reduced sulphur levels in both gasoline and diesel fuels are expected to provide substantial benefits to Ontario's air quality. For example and as estimated in Ontario's *"Anti-Smog Action Plan: Progress Through Partnership"* (http://www.ene.gov.on.ca/envision/air/smog/asap2002.htm), NO_x and VOC emissions from mobile sources are expected to drop by an estimated 50 per cent between now and 2015; and SO_2 emissions are expected to drop from 11 kilotonnes in 2000 to 4 kilotonnes by the end of 2005 and thereafter.

For a comprehensive account of the federal government's clean air initiatives, see "The "Government of Canada's Interim Plan 2001 on Particulate Matter and Ozone," available at http://www.ec.gc.ca/air/pdfs/200104_e.pdf or "Clean Air in Canada: 2003 Progress Report on Particulate Matter and Ozone" available at http://www.ec.gc.ca/air/PM_resp_03/toc_e.html.

5.2.2 VOC Emission Reduction Agenda for Commercial and Consumer Products

In March 2004, the Federal Agenda on the Reduction of Emissions of Volatile Organic compounds from Consumer and Commercial Products was published as a Notice of Intent in Part 1 of the Canada Gazette. Environment Canada and Health Canada are

working together to develop and implement a series of measures between 2004 and 2010 to reduce emissions of VOCs.

Ontario has put in place regulations on gasoline volatility and gasoline vapour recovery to reduce VOCs. Ontario continues to work on developing an Ontario VOC emission reduction plan to address the large number of emission sources.

5.2.3 GHG Emission Reduction Agenda

Fuel combustion and other industrial processes generate both greenhouse gases (GHGs) and smog pollutants. Therefore, actions to reduce GHGs often have the co-benefit of reducing smog-related pollutants.

Over the next five years, the Federal 2005 Budget provides for more than $5 billion in environmental spending, including $3 billion in new investments to address climate change and to protect the natural environment. Additional funds that could have climate change benefits include: Federation of Canadian Municipalities "Green Municipal Funds" (additional $300 million); gas tax revenue transfer ($5 billion); Sustainable Energy Science and Technology Strategy ($200 million); targeting $350 million from the Canada Strategic Infrastructure Fund for the TTC. Many of these actions are expected to lead to reductions in smog pollutants. Federal funding for ethanol production will also help reduce particulate matter formation from vehicles.

On April 13, 2005 the federal government released *Moving Forward on Climate Change: A Plan for Honouring Our Kyoto Commitment*, available at http://www.climatechange.gc.ca/english/newsroom/2005/plan05.asp. The document lays out a framework for actions to achieve Canada's Kyoto target.

5.3 Actions in the United States

5.3.1 The U.S. Clean Air Act

In the U.S., the Clean Air Act (CAA), which is administered and enforced by the Environmental Protection Agency (U.S. EPA), regulates the release of pollutants into the atmosphere. Amongst others, the CAA includes provisions dealing with: the attainment of National Ambient Air Quality Standards (NAAQS) determined from air quality data measurements; the control of mobile sources, hazardous air pollutants and acid deposition; the establishment of a permitting program; and stratospheric ozone protection.

The CAA also provides for interstate commissions on air pollution control, which are to develop regional strategies for cleaning up air pollution. It includes other provisions to petition for actions to reduce interstate air pollution.

Of significant importance to Ontario and Canada is section 115 of the CAA which contains a specific provision related to International Air Pollution. Section 115 requires

the U.S. EPA Administrator to act if he or she has reason to believe that air pollutants emitted in the U.S. cause or contribute to air pollution that may endanger public health or welfare in a foreign country. A foreign jurisdiction may petition the Administrator to enforce the obligation set out in Section 115. Ontario filed one Petition under Section 115 of the Clean Air Act on April 7, 1988, requesting that the Administrator of the EPA undertake a "Rulemaking" to reduce the emission of pollution from the U.S. that was causing acid rain in Canada. At the same time, Petitions were also filed by a number of states including New York, Minnesota, Connecticut, Vermont, New Hampshire, Massachusetts, New Jersey, Maine and Rhode Island, and by the Natural Resources Defense Council and non-governmental organizations. The Administrator of the EPA refused to act on the Petitions.

States have to develop State Implementation Plans (SIPs), requiring approval from the U.S. EPA, that explain how each state will achieve the limits set out in the NAAQS. Of particular significance is the 'NO_x SIP Call Rule', a Rule to reduce NO_x emissions from certain states that "contribute significantly" to the non-attainment of ozone standards in certain downwind states. The Rule applies to 21 states and the District of Columbia and requires each of the states subject to the Rule to reduce NO_x emissions from sources within the state. It was challenged in the courts by a number of U.S. states and electrical utilities. Ontario and Canada filed briefs in support of the U.S. EPA Rule which was sustained through a United States Supreme Court decision in March 2001. The Rule became law on May 31, 2004.[30]

5.3.2 Recent Initiatives of the EPA

5.3.2.1 U.S. New Source Review Program

The U.S. EPA's New Source Review (NSR) permitting program requires industrial facilities to install modern pollution control equipment whenever a new source is built or when an existing source makes a major modification that significantly increases emissions. Each state or local permitting authority is required to incorporate basic NSR program requirements into its SIP. The U.S. EPA finalized a series of reforms to the NSR program in 2002 and 2003, which have been criticized as relaxing environmental requirements.

After the release of the final rules in October 2003, a number of states and environmental groups filed suits in the Court of Appeals for the District of Columbia Circuit challenging the rules, including the Equipment Replacement Provision (ERP) of the NSR rule. On December 24, 2003, the Court stayed the effective date of the October 2003 Equipment Replacement Provision (ERP) of the NSR rule.

[30] In addition to the Petitions described above, Ontario was involved with other legal interventions in the U.S. to reduce transboundary air pollution including the Detroit Incinerator Litigation (1986-1994) and National Ambient Air Quality Standards (1995-1997).

At the same time, the group of states and environmental groups also petitioned the U.S. EPA to reconsider the revisions to the NSR. As a result, on June 29, 2004, U.S. EPA posted for reconsideration the Equipment Replacement Provisions (ERP) of the NSR rule. The U.S. EPA accepted additional comments on three narrow issues concerning ERP amendments. A final decision by the U.S. EPA on the reconsideration was expected by December 28, 2004 (180 days after the reconsideration notice was posted).

U.S. EPA's final decision was delayed. On June 6, 2005 the U.S. EPA issued its final response on the reconsideration of the Equipment Replacement Provision (ERP), as part of the Agency's New Source Review (NSR) permitting program. After evaluating the comments received during the reconsideration process, U.S. EPA has decided not to change any aspect of the ERP as it was originally issued in 2003.

5.3.2.2 U.S. Clean Air Rules

The U.S. EPA announced the Clean Air Rules of 2004 in April 2004. The rules encompass the following inter-related rules: Clean Air Interstate Rule (CAIR); Mercury Rule; Nonroad Diesel Rule; Ozone and Fine Particulate Rules.

The Clean Air Interstate Rule was formally proposed by the U.S. EPA on January 30, 2004 (as the Interstate Air Quality Rule).

On March 10, 2005, Acting EPA Administrator Steve Johnson signed the final Clean Air Interstate Rule. CAIR will reduce and permanently cap emissions of SO_2 and NO_x in the eastern United States. By 2015, CAIR will provide health and environmental benefits valued at over 25 times the cost of compliance.

CAIR will mandate the largest reduction in U.S. air pollution since the reductions set by the U.S. Acid Rain Program under the Clean Air Act Amendments of 1990. When fully implemented by 2015, CAIR will reduce SO_2 emissions in 28 eastern states and the District of Columbia by over 70 per cent and NO_x emissions by over 60 per cent from 2003 levels.

SO_2 emissions are expected to be reduced by 3.6 million tons in 2010 (approximately 40 per cent below current levels) and by another 2.5 million tons per year when the rules are fully implemented (approximately 70 per cent below current levels) in 2015.

NO_x emissions would be cut by 1.6 million tons in 2009 and another 1.3 million tons annually in 2015, about 60 per cent below current levels.

The U.S. EPA analysis shows that if emissions trading is adopted, power plants may use banked allowances to meet compliance in the early year. Therefore, the actual emission reductions could be delayed and full reductions will not be realized in 2015.

In May 2004, the U.S. EPA proposed additional details and rule text supplementing its January 2004 proposal. This supplemental proposal includes regulatory text for model multi-state cap and trade programs to reduce NO_x and SO_2 emissions from power plants.

The Clean Air Act requires certain existing sources of air pollution that impact visibility to meet Best Available Retrofit Technology (BART) requirements. The Regional Haze Program requires the use of BART and allows sources to implement alternatives to BART. In this supplemental proposal, the U.S. EPA proposes considering emissions reductions from power plants under the Clean Air Interstate Rule achieved by a cap and trade program as "better than BART" hence satisfying BART requirements.

The Mercury Rule was also formally proposed by the U.S. EPA in January 2004.

On March 15, 2005, Acting Administrator Steve Johnson signed the final Clean Air Mercury Rule (CAMR) that will reduce mercury emissions from coal-fired power plants across the U.S. Taken together, the recently issued Clean Air Interstate Rule and the new Clean Air Mercury Rule will reduce electric utility mercury emissions by nearly 70 per cent from 1999 levels when fully implemented in 2018.

CAMR limits mercury emissions from new and existing coal-fired power plants, and creates a market-based cap-and-trade program that will permanently cap utility mercury emissions in two phases: the first phase cap is 38 tons beginning in 2010, with a final cap set at 15 tons beginning in 2018.

Internal U.S. EPA analysis suggests the cap-and-trade option will deliver an actual pollution reduction of only 50 per cent by 2018 and that the 70 per cent target would not be reached by 2025 and perhaps not until after 2030.

The ***Nonroad Diesel Rule*** proposed emission standards for diesel engines used in most kinds of construction, agricultural and industrial equipment. The proposed standards would take effect for new engines starting as early as 2008 and be fully phased in by 2014. This initiative is expected to reduce emissions from nonroad diesel engines by 90 per cent by 2010. To avoid damages by sulphur (in the fuel) to emission control equipment used to achieve these standards, U.S. EPA also proposed to reduce the allowable level of sulphur in nonroad diesel fuel by more than 99 per cent by 2010. The U.S. EPA released the final nonroad diesel rules in May 2004.

The ***Ozone Rules*** and ***Fine Particulate Rules*** will designate those areas in the U.S. that do not meet the current health based standards for ozone and fine particulate matter ($PM_{2.5}$). This will require states to submit SIPs to reduce the levels or ozone and/or fine particulate matter where the standards are not met. In April 2004, U.S. EPA designated areas in 31 states as not meeting the new health standards for ozone (i.e., non-attainment areas).

In February 2004, the states identified to U.S. EPA areas to be designated as non-attainment areas for fine particulates. U.S. EPA reviewed these recommendations and

took final action in December 2004 to designate attainment and non-attainment areas for fine particles. Twenty states and their 225 counties (including the District of Columbia) were designated as non-attainment areas, indicating that they would have to take actions to improve their air quality to meet the $PM_{2.5}$ air quality standards. By law, non-attainment areas are subject to a number of requirements to reduce particles and the pollutants that form them.

The current U.S. NAAQS are not as stringent as the current Canada-Wide Standards for ozone and $PM_{2.5}$. Nevertheless, the development and implementation of SIPs in accordance with the Clean Air Ozone and $PM_{2.5}$ Rules will help reduce the transboundary flow of smog precursors to Ontario and, thereby, improve the ambient air quality in Ontario.

5.4 Joint Canada-U.S. Actions: Canada-U.S. Air Quality Agreement

Canada and the U.S. established the *Canada-U.S. Air Quality Agreement* in March 1991 to address transboundary air pollution. Initially, the focus of the Agreement was on acid rain with an Acid Rain Annex that was part of the original Agreement. In December 2000, an Ozone Annex was also developed by the two countries as part of the Agreement.

5.4.1 Acid Rain Annex

The key U.S. commitments under the Acid Rain Annex include a reduction of sulphur dioxide (SO_2) emissions by 10,000 kilotons from 1980 levels by 2000, taking into account credits (allowances) earned from 1995 to 1999; achievement of a permanent national cap of 8,950 kilo-tons per year for electric utilities by 2010; and, a national SO_2 cap of 5,600 kilo-tons per year for industrial sources beginning in 1995.

The key Canadian commitments under the Acid Rain Annex include a reduction of sulphur dioxide (SO_2) emissions in the seven eastern-most provinces to 2,300 kilotonnes (kt) per year by 1994 and maintenance of the 2,300 kt cap to December 1999; achievement of a permanent national SO_2 cap of 3,200 kt per year by 2000 ; an interim reduction of national nitrogen oxides (NO_x as NO_2) emissions from stationary sources by 100 kt below the year 2000 forecasted level of 970 kt per year; develop further annual national emissions reduction requirements from stationary sources to be achieved by 2000 and/or 2005; and, implement a NO_x control program for mobile sources.

5.4.2 Ozone Annex

The key U.S. commitments under the 2000 Ozone Annex include implementation of the NO_x SIP Call requirement which is expected to reduce summertime NO_x emissions in the U.S. transboundary region; NO_x and VOC reductions associated with existing U.S. vehicle and fuel quality rules and with standards for new and modified stationary sources; and, VOC reductions associated with standards for stationary sources of hazardous air

pollutants, consumer and commercial products, architectural coatings and automobile repair coatings.

The key Canadian commitments under the Ozone Annex include: annual caps by 2007 of 39 kt of NO_x (as NO_2) from fossil fuel power plants in central and southern Ontario and 5 kt of NO_x in southern Quebec; new stringent emission reduction standards regulated to align with the U.S. to reduce NO_x and (VOCs) from vehicles and fuels including cars, vans, light duty trucks, off-road vehicles, small engines, diesel engines and fuel; and, measures required to attain the CWS for ozone to address NO_x emissions from industrial boilers and VOC emissions from solvents, paints, and consumer products.

Ontario has taken a number of initiatives to reduce its emissions of VOC and NO_x, in support of the Ozone Annex. These include the *Drive Clean* vehicle inspection and maintenance program, stage 1 vapour recovery (gasoline), gas volatility and environmental training for dry cleaners. In addition, Ontario has adopted CCME guideline A-5 for new and modified combustion turbines and CCME guideline A-9 for new commercial/industrial boilers and heaters, and as indicated earlier, implemented an Emissions Trading Regulation which caps NO_x (as NO) and SO_2 emissions from the electricity sector. Lastly, the mandatory emissions monitoring and reporting regulation adopted by Ontario in 2001 provides a more accurate account of VOC and NO_x emissions across the province.

Phasing out coal will support the Acid Rain, Ozone and Particulate Matter Annexes. It will result in significant reductions in SO_2 (precursor to acid rain and particulate matter), NO_x (precursor to acid rain, ozone and particulate matter), and particulate matter.

5.4.3 Future Particulate Matter Annex

Based on a joint review of technical and scientific information, Canadian and U.S. co-chairs of the Air Quality Committee recommended to the Canadian Minister of the Environment and the Administrator of the U.S .EPA that consideration should be given to the negotiation of an Annex to deal with the issue of particulate matter in the Canada – U.S. Transboundary Region, pursuant to the Air Quality Agreement. In August 2004, Minister Dion and Administrator Leavitt endorsed the recommendation of the Air Quality Committee.

6.0 Conclusions

This current review of transboundary air pollution impacts from Ontario's perspective indicates:

- Unique features exist in the regional climate that lead to elevated episodic conditions of poor air quality over southern Ontario. Transboundary transport of pollution is a very significant source of regionally elevated air quality levels in Ontario.

  Observational evidence, based on air quality and meteorological considerations, is persuasive that elevated levels of smog (both ground-level ozone and fine particulate matter), airborne acidic pollutants and hazardous air pollutants such as mercury in Ontario are strongly linked to long-range transport and transboundary flow from the highly industrialized and urbanized areas of the neighbouring U.S. states. Such qualitative assessment of the impact on Ontario can also be seen in the quantity of emissions that are released in the air shed that are of U.S. origin compared to those of Ontario.

- Detailed understanding of the role and the quantification of transboundary contributions to air quality levels in Ontario is provided by regional mathematical models of atmospheric transport and transformation. As ozone and fine particulate matter have a large number of sources in common, similarities are seen in the modelling results.

  Under episodic conditions for the May to September period, the contribution from Ontario sources, as confirmed by modelling, is limited whereas transboundary contribution dominates. For days of high ozone concentration, Ontario contribution ranges from 1 per cent in the Windsor area, 9 per cent in the GTA, to about 16 per cent downwind of Toronto. Moreover, Ontario's contribution to upper New York state and Vermont/New Hampshire is very small, approximately 4 per cent and 3 per cent, respectively. On days of high $PM_{2.5}$, Ontario emissions contribute 50 per cent to concentrations in the GTA, and the contributions are much smaller in the remainder of the study area, especially around Windsor and for regions in the U.S.

  When all days are considered during the May to September period, Ontario's percentage contribution to $PM_{2.5}$ is larger. The larger percentage contribution is to be expected since the average concentrations over the five month period are significantly lower than those expected on episode days.

  Ontario understands that it is not only the recipient of transboundary air pollution, but the province contributes to the problem in downwind jurisdictions such as Quebec, the U.S. New England states and the Canadian maritime provinces. Modelling results show that Ontario's emissions contribute to approximately 16

per cent of $PM_{2.5}$ loadings on average days in Quebec and at most, 12 per cent on days when ozone and $PM_{2.5}$ concentrations were high. Ontario emissions contribute up to approximately 20 per cent of the $PM_{2.5}$ loadings on average days in the upper state New York area and about 7 per cent in Vermont and New Hampshire.

Since ozone and $PM_{2.5}$ potentially cause health impacts at all concentrations (i.e. they do not have health thresholds), continued improvement of air quality on both cleaner and dirtier days will provide benefits.

In summary, measurements and modelling considered in conjunction provide very compelling evidence concerning the impact of transboundary transport in Ontario.

- Based on 2003 demographics, Ontario is incurring almost $9.6 billion in health and environmental damages each year due to the impact of ground-level ozone and fine particulate matter. Of this total, approximately 55 per cent is attributable to transboundary air pollution. The remainder is attributable to provincial emissions of these air pollutants.

  Health damages comprise approximately 70 per cent of the total economic damages or about $6.6 billion per year, of which $3.7 billion is attributed to transboundary air pollution and $2.9 billion to provincial emissions. The great majority of the economic losses associated with health damages are attributable to premature mortality. Of a predicted 4,881 premature deaths, 56 per cent or 2,751 are associated with transboundary air pollution, and more specifically with $PM_{2.5}$. This result is common with health damage assessments, which have been undertaken elsewhere in Canada, the U.S. and Europe.

  The distribution of these damages and the proportions attributable to the two sources vary considerably among the various regions of the province. As expected, southwestern Ontario experiences a large proportion of damages attributable to U.S. emissions, whereas the greatest impacts of air pollution originating in Ontario are felt in South Central Ontario, comprised mainly of the Greater Toronto Area. The economic damages incurred in the South Central Ontario area represent 61 per cent of the total damages.

- Key actions being taken and being considered in Ontario, Canada and the U.S. in addressing transboundary pollution consist of :

  A multi-faceted, comprehensive smog reduction approach that addresses multiple pollutants (some common to smog and acid rain) has been adopted. The government's key smog-causing emission reduction activities can be grouped into eight categories: (1) Regulatory Initiatives; (2) Government leadership; (3) Conservation; (4) Clean energy incentives; (5) Public education and outreach; (6) Encouraging non-regulatory commitments; (7) Building capacity; and (8) Agreements between Ontario and other provincial/state jurisdictions.

Ontario works closely with the federal government to encourage the use of appropriate federal tools in reducing emissions affecting Ontario's air quality such as cleaner vehicle engines and fuels, federal VOC Agenda for Commercial and Consumer Products, and the Federal GHG Agenda, as well as to initiate discussions with the U.S. on transboundary anti-smog actions when necessary and appropriate.

Actions in the U.S. that relates to potential air quality improvements in Ontario fall under activities of the U.S. Clean Air Act and recent initiatives of the EPA such as the U.S. New Source Review Program, and the new U.S. Clean Air Rules.

There are also joint Canada-U.S. actions such as the Canada-U.S. Air Quality Agreement that has been established to address transboundary pollution (this includes the Acid Rain Annex and the Ozone Annex).

Ontario is a vast and industrially diverse community with a history of environmental stewardship. To meet the challenges posed by air pollutants transported across borders, new processes and partnerships reflective of the regional nature and complexity of the issue are required.

There is an urgency to address the unacceptable health impacts and environmental consequences.

7.0 Abbreviations and Acronyms

AAQC	Ambient Air Quality Criteria (Ontario)
ADOM	Acid Deposition Oxidant Model
AQI	Air Quality Index (Ontario)
ASAP	Anti-Smog Action Plan (Ontario)
BART	Best Available Retrofit Technology (U.S. EPA)
CAA	Clean Air Act (U.S.)
CAAP	Clean Air Action Plan (Ontario)
CAIR	Clean Air Interstate Rule (U.S. EPA)
CAMNet	Canadian Atmospheric Measurement Network
CAPMoN	Canadian Air and Precipitation Monitoring Network
CCME	Canadian Council of Ministers of the Environment
CEPA	Canadian Environmental Protection Act
CMAQ	Community Multi-Scale Air Quality Model (U.S. EPA)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRESTech	Centre for Research in Earth and Space Technology
CWS	Canada-wide Standard
DDT	Dichlorodiphenyltrichloroethane
EC	Environment Canada
ERP	Emission Reduction Plan (Ontario)
ERP	Equipment Replacement Provisions (U.S. EPA)
GHG	Greenhouse Gas

GTA	Greater Toronto Area
Hg	Mercury
Hg^0	Elemental Mercury
Hg^{2+}	Bivalent form of mercury as either mercury oxide (HgO) or mercury choloride ($HgCl_2$)
HNO_3	Nitric Acid
H_2SO_4	Sulphuric Acid
kg/ha/yr	kilogram per hectare per year
kt	kilotonne
MACT	Maximum Achievable Control Technology
$\mu g/m^3$	microgram per cubic metre
mg/kg	milligram per kilogram
MOE	Ministry of the Environment (Ontario)
MOU	Memorandum of Understanding
MT	Megatonnes
MW	Megawatts
NAAQS	National Ambient Air Quality Standard (U.S.)
ng/L	nanogram per litre
ng/m^3	nanogram per cubic metre
NH_3	Ammonia
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_3^-	Nitrate

NO_x	Nitrogen Oxides ($NO + NO_2$)
NSR	New Source Review (U.S.)
O_3	Ozone
OMA	Ontario Medical Association
OPG	Ontario Power Generation
PCB	Polychlorinated Biphenyls
PM	Particulate Matter
$PM_{2.5}$	Particles less than 2.5 microns in diameter
PM_{10}	Particles less than 10 microns in diameter
POPs	Persistent Organic Pollutants
ppb	part per billion
RFP	Request for Proposal
SARP	Smog Alert Response Program
SIP	State Implementation Plan (U.S.)
SO_2	Sulphur Dioxide
SO_4^{2-}	Sulphate
U.S. EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds

8.0 Glossary

Acid Aerosol	Dispersion of fine particles (smoke) or fine droplets (fog) in air which are acidic. Examples include fine particulate sulphate compounds and sulphuric acid mists.
Acidic Deposition	Refers to deposition of a variety of acidic pollutants (acids or acid-forming substances such as sulphates and nitrates) on biota or land or in waters of the Earth's surface. Deposition occurs in the dry form (fine particulate and gases) or in the wet form (rain/snow), commonly known as acid rain.
Acid Deposition Oxidant Model (ADOM)	A regional air quality model developed in the 1980s and early 1990s by a number of groups including the Ontario Ministry of the Environment and Environment Canada. The model takes primary emissions throughout a region, along with meteorological data, and simulates air concentrations and deposition of contaminants across a region. The model has been used extensively for acid deposition and oxidant assessments.
Acid Gas	A gas such as sulphur dioxide (SO_2) or nitrogen dioxide (NO_2) which is transformed into acidic substances such as sulphuric (H_2SO_4) and nitric acid (HNO_3).
Airshed	A geographical region of influence, or spatial extent of the air pollution burden.
Air Toxics	Airborne pollutants that can cause health effects such as cancer, genetic mutations, organ damage, changes to the nervous system, or even physiological harm as a result of prolonged exposure, even to relatively small amounts.
Ambient Air	Outdoor or open air.

Anthropogenic	Arising as a result of human activity.
Canadian Acid Precipitation Monitoring Network (CAPMon)	A monitoring network with a number of sites across Canada located away from local emission sources. The network is used to assess regional spatial patterns and temporal trends in pollutants related to acid deposition and smog.
Climate Change	Changes to normal weather or climate patterns due to global warming/cooling.
Cloud Water	Droplets of water in clouds. Water droplets in clouds are the starting point for the formation of precipitation.
Community Multi-scale Air Quality Model (CMAQ)	A regional air quality model developed by the U.S. EPA. The model takes primary emissions throughout a region, along with meteorological data, and simulates the air concentrations and deposition of contaminants, including ozone and fine particulate matter, across the region.
Continuous Monitoring	Measurements of air quality parameters taken on a continuous basis with an automated air monitoring system. The results are usually reported as hourly averages. Over a 1 year (365 days) period, a perfect data set would yield 8760 hourly averages.
Criterion	Maximum concentration or level (based on potential effects) of contaminant that is desirable or considered acceptable in ambient air. Not legally enforceable, like regulatory standards, unless included in a regulatory instrument. In Ontario, referred to as Ambient Air Quality Criterion (AAQC).

Critical Load	The highest load that will not cause chemical changes leading to long-term harmful effects in the most sensitive ecological systems.
Dry Deposition	The process by which particles or gases such as SO_2 are removed from the atmosphere by deposition or adsorption to the Earth's surface in the absence of precipitation.
Eulerian Model System	A three dimensional grid of cells across a region. Regional atmospheric models simulate the chemical transformations of primary emissions into these fixed grid cells and the transport and deposition of contaminants throughout the domain of the grid cells.
Exceedance	Violation of air pollutant levels permitted by environmental protection criteria, objectives or standards.
Fine Particulate Matter	Particles smaller than about 2.5 microns in diameter, which arise mainly from condensation of hot vapors and chemically driven gas-to-particle conversion processes; also referred to as $PM_{2.5}$. These are fine enough to penetrate deep into the lungs and have the greatest effects on health. Also known as respirable particulate matter.
Fossil Fuels	Natural gas, petroleum, coal and any form of solid, liquid or gaseous fuel derived from such materials for the purpose of generating heat.

Grasshopper Effect	Persistent and volatile pollutants – including certain pesticides, industrial chemicals and heavy metals – evaporate out of the soil in warmer countries where they are still used, and travel in the atmosphere toward cooler areas, condensing out again when the temperature drops. The process, repeated in "hops", can carry them thousands of kilometres in a matter of days. Canada's cold climate puts it at the receiving end of this process, with measurable concentrations of DDT, toxaphene, chlordane, PCBs and mercury found in both the Great Lakes and the Arctic (source: Environment Canada).
Global Warming	Long-term rise in the average temperature of the Earth; principally due to an increase in the buildup of carbon dioxide and other green house gases, such as methane and nitrous oxide.
Ground-level Ozone	Colorless gas formed from chemical reactions between nitrogen oxides and hydrocarbons (volatile organic compounds) in the presence of sunlight near the Earth's surface.
Hazardous Pollutant	Pollutant that can be hazardous to human and/or animal health.
Heavy Metals	Metallic elements with high atomic weights (e.g., mercury, chromium, cadmium, arsenic, and lead) that tend to be toxic and bioaccumulate.
Hydroxyl Radical	A single hydrogen atom and a single oxygen atom bound together. It is responsible for the oxidation of most of the compounds that are released into, or formed, in the atmosphere.
Inhalable Particles	Represent up to 60 per cent of the total suspended particulate matter; composed of both coarse (diameter 2.6 to 10.0 microns) and fine (diameter < 2.5 microns) particles; also referred to as PM_{10}.

Kilotonne	One thousand metric tonnes or one thousand and one hundred tons.
Lake Acidification	The process by which a lake becomes acidified due to its inability to counteract or neutralize acid inputs. A lake is deemed to be acidified when its pH is less than 6.
Leaching	Pertaining to the losses of soluble matter as a result of the filtering through water; dissolving or being washed away.
Methylmercury	Biologically available form of mercury produced by microorganisms; at pH less than 7 it occurs as CH_3Hg^+ which is a powerful human neurotoxin. It concentrates up the food chain and is also absorbed by fish through their gills.
Micron	A millionth (10^{-6}) of a meter.
Nitrates	Compounds containing the radical (NO_3^-). Most are soluble in water and when converted to nitric acid (HNO_3) can acidify sensitive aquatic ecosystems.
Non-ferrous	Not composed of or containing iron.
Oxidants	Air pollutants, such as ozone, with a great tendency to oxidize other species.
Ozone Episode Day	A day on which widespread (hundreds of kilometres) elevated ozone levels (greater than 80 ppb maximum hourly concentration) occur simultaneously.
Ozone Exceedance Day	A day on which there is at least one hour with an ozone concentration greater than the 1-hour Ontario AAQC of 80 ppb.

Ozone Scavenging	The decrease in the concentration of ground-level ozone from chemical reactions with ambient concentrations of nitric oxide (NO). This scavenging effect explains the lower concentrations of ozone in urban compared to rural environments.
Particulate Matter	Refers to all airborne finely divided solid or liquid material with an aerodynamic diameter smaller than 100 microns.
Percentiles	Obtained from the ranking of data points in percentage categories for the entire data set. The value of the 50^{th} percentile is the median of that data set, i.e. half the data points are below/above that value. For the 98^{th} percentile value, 2 per cent of the data points are equal to or greater than that value.
Persistent Organic Pollutants (POPs)	Chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment.
pH	A logarithmic measure of the hydrogen ion concentration on a scale of 0 to 14; used to gauge the acidity (pH < 7) or alkalinity (pH> 7) of a solution. A neutral solution has a pH of 7.
Photochemical Reaction	Chemical reaction influenced or initiated by light, particularly ultraviolet light.
Photochemical Smog	See smog.
Precursor Pollutant	Usually a primary pollutant which can be transformed (or enable the transformation) into secondary pollutants.
Primary Pollutant	Pollutant emitted directly to the atmosphere such as sulphur dioxide.

Polychlorides	Compounds which include more than one chlorine atom.
Reduced Visibility	Occurs as a result of the scattering and absorption of light by particles and gases in the atmosphere; commonly known as regional haze which can be whitish or brownish in appearance depending on the particulate and gaseous components responsible for scattering/absorbing the light.
Respirable Particles	See Fine Particulate Matter.
Secondary Pollutant	Pollutant formed from other pollutants in the atmosphere.
Smog	A concentration of smoke and fog; colloquial term used for photochemical fog, which includes ozone and other contaminants such as fine particulates; tends to be a brownish haze.
Stratosphere	Atmosphere 10 to 40 kilometres above the Earth's surface.
Stratospheric Ozone	Ozone formed in the stratosphere from the conversion of oxygen molecules by solar radiation; ozone found there absorbs much ultraviolet radiation and prevents it from reaching the Earth.
Sulphate	A compound containing the sulphate radical $(SO_4)^{-2}$. When combined with moisture in the air, it is transformed to sulphuric acid (H_2SO_4) which can acidify sensitive aquatic ecosystems when deposited to ground.
Volatile Organic Compounds	Organic substances with a sufficiently high vapour pressure to volatilize to the atmosphere. These are present in organic solvents and motor vehicle liquid fuels such as gasoline. Some play an important role in the formation of ozone and smog aerosols.

Wet Deposition	The process by which particulate or gaseous material is removed (scavenged) from the atmosphere to the Earth's surface during precipitation (rain or snow).

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Appendix 1: A Detailed Modelling View of an Air Pollution Episode

In mid-July 1998 an air pollution episode occurred, triggering a smog advisory across southern Ontario. As part of the five-month modelling exercise described in Chapter 3, MOE modellers examined the July episode in greater detail. This appendix outlines the type of additional information modelers are able to glean from such studies.

In the figure below, predicted contributions are displayed for sulphate concentrations in air across the region, for state groupings during a period of relatively high sulphate concentrations. There are six maps giving the percentage contributions for the emission regions given in the upper left; Illinois and Indiana, New York and Pennsylvania, Michigan, Ohio and West Virginia, Kentucky and Tennessee and for Ontario. The composite predicted sulphate air concentrations are shown in the upper right. During this period (July 15, 1998) the greatest impact on Ontario is from Ohio and West Virginia. Illinois, Indiana and Michigan have some impact on this episode day while New York, Pennsylvania, Kentucky and Tennessee little or no impact. Ontario emissions are seen to have a small impact on eastern Ontario and the most northerly parts of New York State.

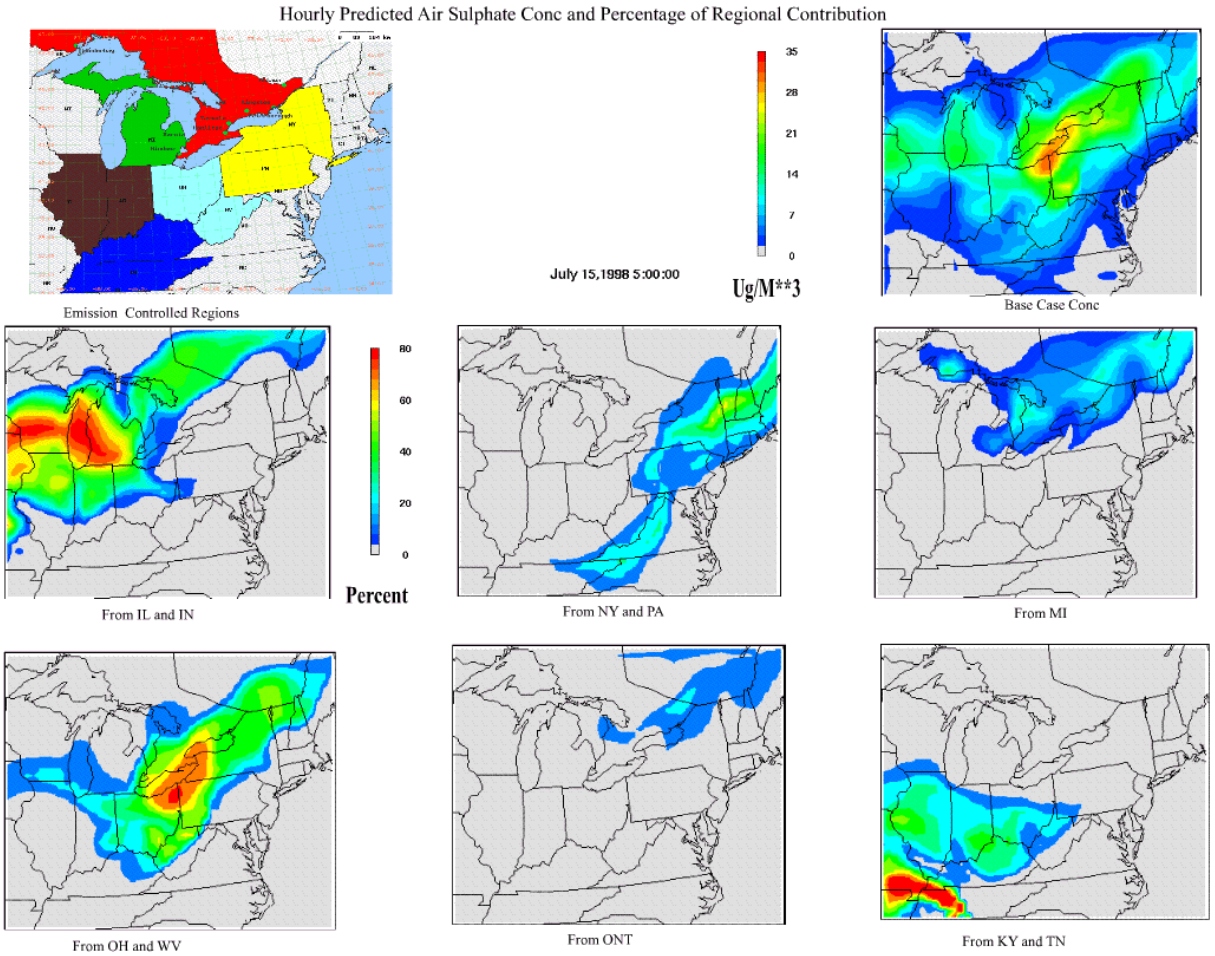

Figure A-1: Regional Contributions to Sulphate During Relatively High Air Sulphate Concentrations in Southern Ontario on July 15, 1998.

(source: Ontario Ministry of the Environment)

In Figure A-2 below, predicted contributions are displayed for sulphate concentrations in air across the region during a relatively low sulphate day in Ontario. Again, the composite is shown in the upper right. During this period (July 17, 1998) the greatest impact on Ontario is from emissions from within Ontario and less so from Michigan Ohio and West Virginia. Impacts from other US states, with the exception of Illinois and Indiana whose emissions sweep first in an easterly direction before moving north and impacting Ontario in the Kingston through Cornwall area of southeastern Ontario, have less impact, and New York, Pennsylvania, Kentucky and Tennessee have little or no impact. Ontario emissions however, are seen to impact on several of the northeastern states on this comparatively clean day.

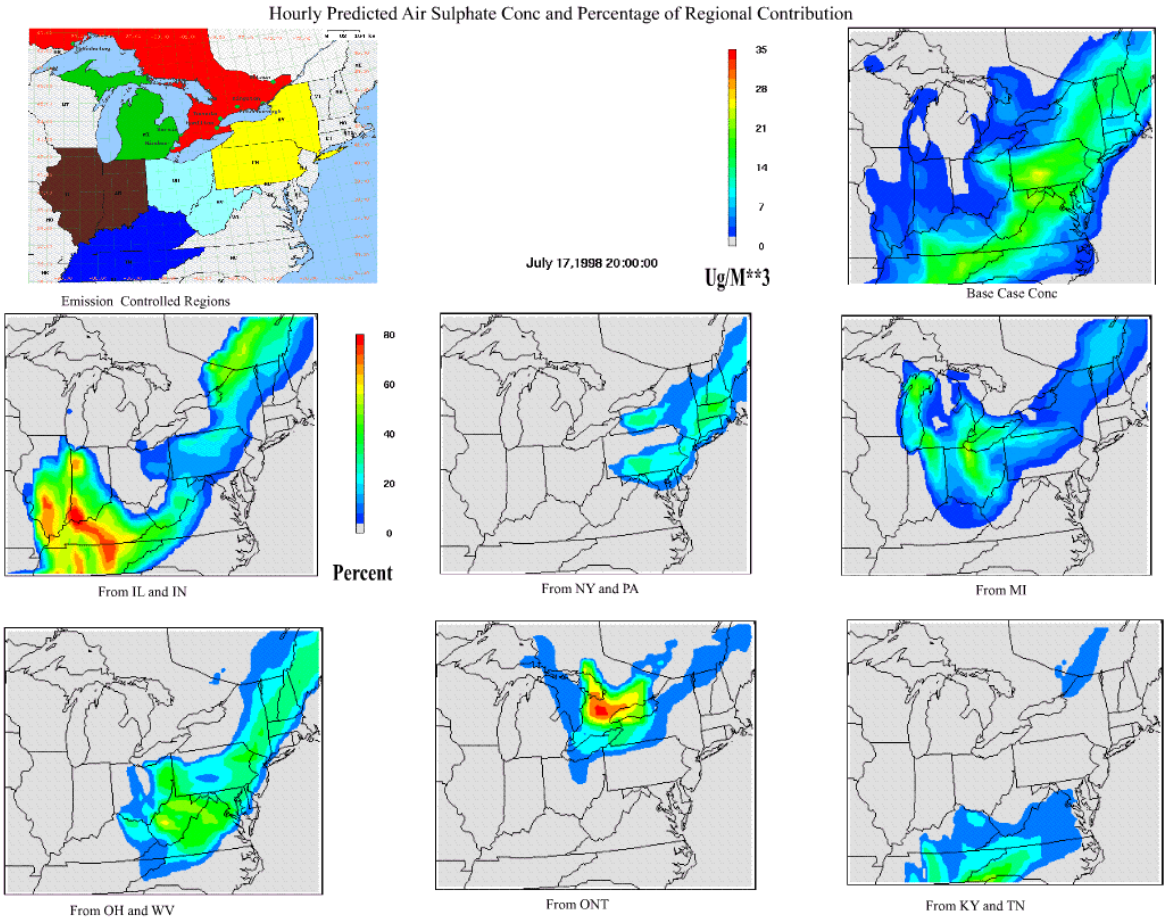

Figure A-2: Regional Contribution of Sulphate During Relatively Low Air Sulphate Concentrations in Southern Ontario on July 17, 1998.

(source: Ontario Ministry of the Environment)

This impact data can be displayed in other ways. In Figure A-3 below the impacts of emissions from the various state groups are displayed as pie charts for selected locations across Ontario and some downwind states on July 16th 1998. The pie slices are colour-coded according to the state colouring seen in the lower right graphic insert. The mid-western US states clearly have the greatest impact. The impact on itself of Ontario's emissions (red wedges) is nowhere in Ontario greater than about 20-25 per cent. Ontario's impact on other jurisdictions, specifically New York State, is at most about 10 per cent in the northern parts of the state. The impact of NY and Pennsylvania emissions on Ontario reaches almost the same level (about 10 per cent) in the Kingston to Cornwall corridor of southern Ontario.

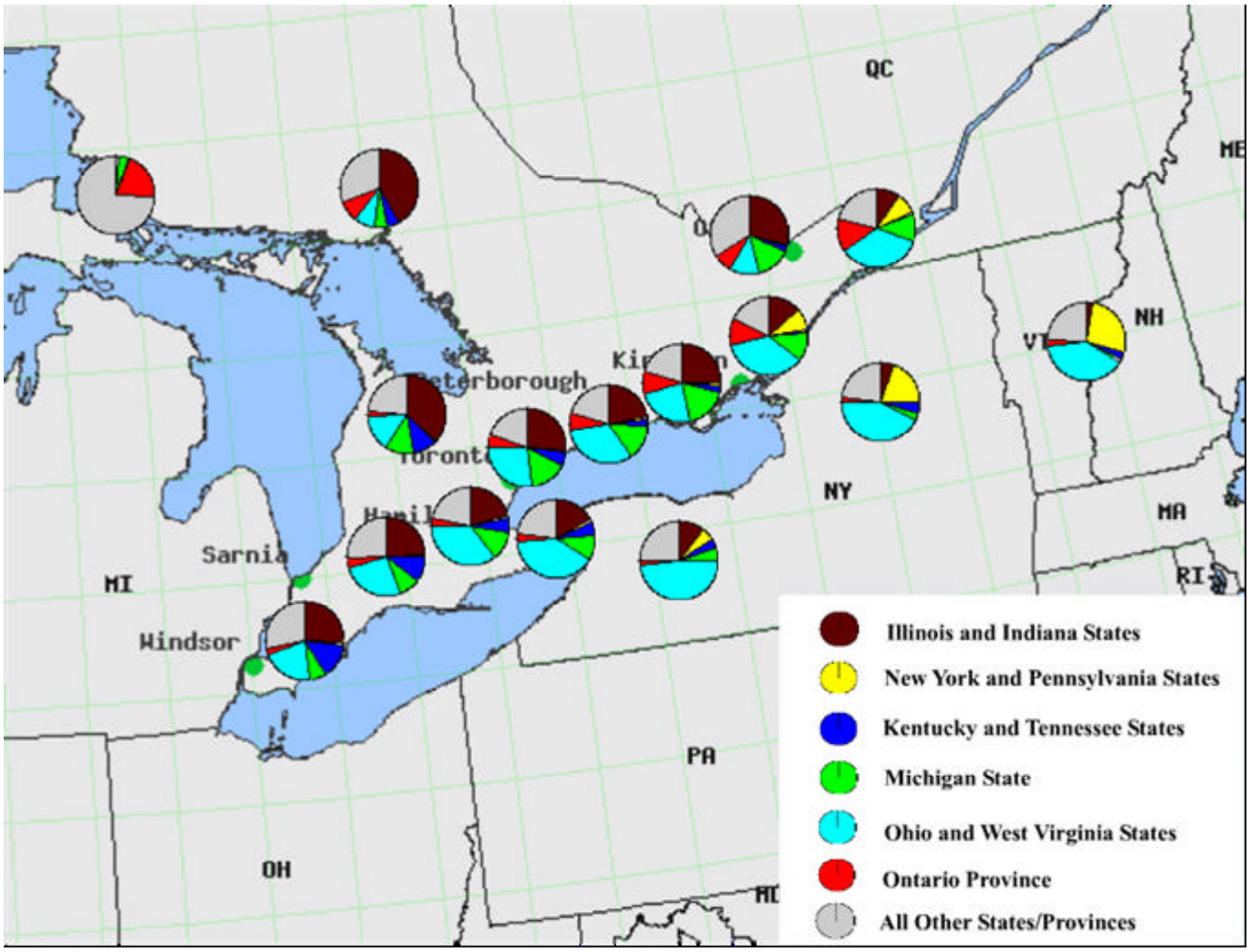

Figure A-3: Regional Contributions to Sulphate at Selected Sites for Predicted Averages on July 16, 1998.
(source: Ontario Ministry of the Environment)

Figure A-4 below offers a partial explanation for the impacts seen above. Sulphur dioxide emissions from power plants in the modelling domain are shown as dots that vary in size according to their annual emissions. Power plants are the major source of sulphur dioxide emissions for the region. Like the main body of modelling data presented in Chapter 3, it is very clear that the impact of emissions from neighbouring US states is so overwhelming that any substantial improvement in Ontario air quality, not just on days when the air quality is poorest, must come through heretofore unachieved reductions in emissions from these states.

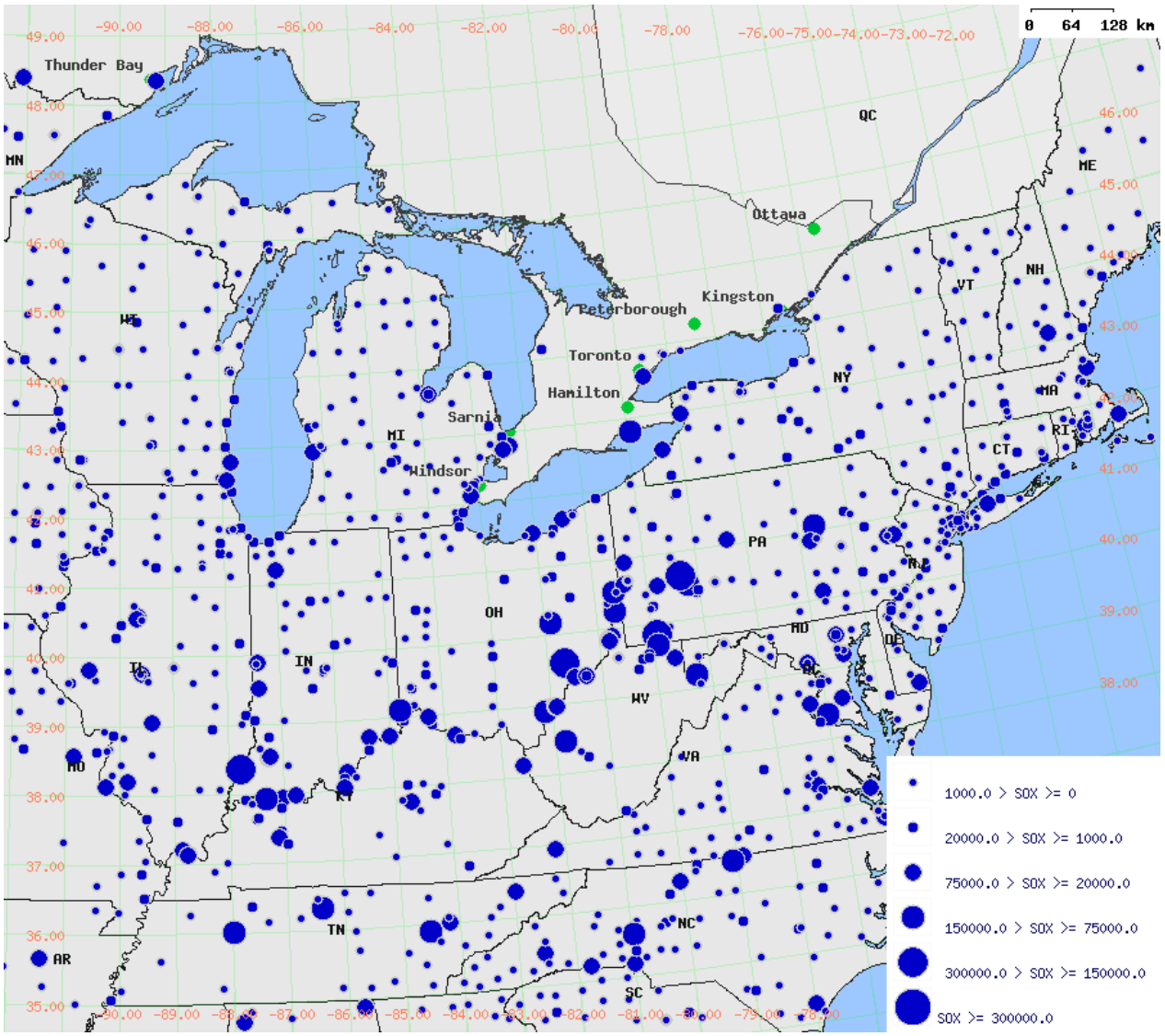

Figure A-4: Sulphur dioxide emissions from power plants shown as dots that vary in size according to their emission inventories
U.S. 1995 (with 2001 updates) and Canada 1999 Emission Inventories
(source: Ontario Ministry of the Environment)

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